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Przygotowanie procesu inwestycyjnego w budownictwie
Realizacja robót budowlanych
Problemy planowania przebiegu przedsięwzięć budowlanych

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PRZYGOTOWANIE PROCESU INWESTYCYJNEGO W BUDOWNICTWIE

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JANUSZ BOCHENEK*

THE SELECTION CRITERIA FOR APPOINTING THE CONTRACTOR FOR BUILDING WORKS IN PUBLIC PROCUREMENT PROCESS IN SELECTED EU COUNTRIES

KRYTERIA WYBORU WYKONAWCY NA ROBOTY BUDOWLANE W PRZETARGACH PUBLICZNYCH W WYBRANYCH KRAJACH UNII EUROPEJSKIEJ

A b s t r a c t

This paper presents an analysis of selected criteria for choosing the most suitable contractor in a public procurement process, and for appointing the contractor whose tender best meets the criteria used in Poland, Germany, United Kingdom and France. The national procurement regulations are based on the European directive 2004/18/EC that allows for an objective multi-criteria assessment of a tender offer. As foreign examples prove, the procedures used in the process of tenders' evaluation, followed by a selection of the best bidder, vary, depending on the country of their application. Moreover, they show that the lowest price is not the most appropriate choice for the contracting authorities, if they adhere to the rule 'value for money'.

Keywords: public procurement, selection of the contractor, criteria of selection

S t r e s z c z e n i e

W artykule przedstawiono analizę kryteriów wyboru odpowiedniego wykonawcy w drodze przetargu publicznego na przykładzie Polski, Niemiec, Wielkiej Brytanii i Francji. Uregulowania zawarte w przepisach krajowych bazują na postanowieniach dyrektywy 2004/18/WE, która zakłada możliwość obiektywnej wielokryteriowej oceny ofert. Zagraniczne przykłady pokazują, że procedury selekcji wykonawców różnią się od siebie znacznie w zależności od kraju stosowania, a najniższa cena nie jest najlepszym wyborem dla zamawiającego i zamawiający stosują zasadę *value for money*.

Słowa kluczowe: przetarg publiczny, wybór wykonawcy, kryteria wyboru

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1. Introduction

The procedures for the award of public works, supply and service contracts in the European Union, relating to the rules of selecting contractors and awarding contracts have been changing throughout the years.

One of the crucial changes was the EU Directive 2004/17/EC [1] introduced in 2004, which referred to the procedure of awarding contracts by the contracting authorities operating within the sectors of the water, energy, transport and postal services, and Directive 2004/18/EC [2] regarding the coordination of procedures for awarding public works contracts for supplies and services. Both of these Directives standardised the procedure for the award of public contracts across all EU countries whereby the Directives have been implemented in their legal systems. Moreover, EU Commission regulation no. 213/2008 [3] introduced Common Procurement Vocabulary (CPV).

In several countries the selection of a contractor is not strictly linked with a price while the applied criteria used in the pre-qualifying procedure and main proceedings aim at selecting competitive ("the most economically advantageous") tender offers which proposes the best price for delivering a particular service or the works within the lifecycle of the service or works. In other words, the offered construction cost is the lowest possible in order to keep the servicing, maintenance and repairs at the lowest possible level during the set time of utilising the building. For the contracting authorities it brings a reduction of risk throughout the duration of the construction process, such as risk related to the utilisation of poorer quality materials, prolongation of a due date, or disputes over additional works. Consequently, it has become necessary to establish a set of transparent criteria for the contractors and to outline the evaluating procedures for these criteria. It has become increasingly apparent across the countries of EU that decisions made strictly in relation to the lowest price is risky and may result in a project's failure.

2. Procedure for selecting tender offer and appointing contractor in selected EU countries

Directive 2004/18/EC of the European Parliament and of the European Council of 31st March 2004 on the coordination of procedures for the award of public works, supply and service contracts obliged EU member states to implement EU directives into their national law systems in order to comply with EU regulations. The directive specifies two types of procedures leading to the award of public contracts: standard procedure (open and restricted procedure) and special procedures (competitive dialogue, negotiated procedure with prior publication, negotiated procedure without publication).

Directive 2004/18/EC highlights the importance of main EU principles of non-discrimination and equal treatment which translate into assessing the offers in light of the principle of effective competition. Consequently, the directive allows for the application of only two contract award criteria: 'the most economically advantageous' tender offer and 'the lowest price'. In relation to 'the most economically advantageous' offer the selection criteria may refer to: quality, price, technical merit, aesthetic and functional characteristics, environmental, characteristics, running costs, cost-effectiveness, after-sales service, technical assistance, delivery date and delivery period or period of completion.

Despite conducting the process of standardisation of the regulations across all EU member states' legal systems, practical realisation of the rules vary between the countries, in relation to the evaluation of offers, selecting tender offers and appointing contractors.

Presented below is a process for appointing contractors in selected European Union member states. The article presents an analysis of public advertisements published by the Official Journal of the European Union from the years 2010 to 2013 and regarding the works for complete or part construction and civil engineering work (CPV 45200000-9). Five types of procedures were taken into consideration: open procedure, restricted procedure, competitive dialogue, negotiated procedure with prior publication, negotiated procedure without publication. The analysis presents the number of procurement processes in each analysed country, identifying the number of appointments based on the 'price criterion', and those based on 'the most economically advantageous tender' criterion.

2.1. Poland

Poland's legislation within the area of public procurement is specified by the Act of Parliament of 29th of January 2004, Public Procurement Law (*Prawo Zamówień Publicznych*) [4].

As the act states, the evaluation criteria may include: price or price and other criteria regarding the object of tendering. The act gives precedence to the price criterion before 'other criteria'. This rule stands in opposition to the EU directive 2004/18/EC where the price is placed in second position. Furthermore, Polish act does not refer to pre-qualifications, meaning – the introductory selection of contractors.

As a common practice the pre-qualifying procedure is not usually conducted and the lowest price is the only assessment criterion.

Table 1 show that between 2010 and 2013 in Poland the majority of procurement processes took form of an open procedure (89.5%). Other processes occurred as follows: restricted procedure – 6.2%, competitive dialogue – 0.6%, negotiated procedure with prior publication – 1.1% and negotiated procedure without publication – 2.6%.

In open tender procedures the price occurred as the only applied criterion in 89.5% of proceedings, and the most economically advantageous tender was chosen in only 10.2% of cases. In restricted tender the tendency proved to be similar and showed the 'lowest price' criterion to be pivotal in 80.2%.

It is noticeable (Table 2) that the number of open and restricted tender procedures based strictly on the price criterion is declining year after year while the number of the tender procedures based on the most economically advantageous tender consistently increases.

T a b l e 1

Selection criteria for appointing the contractors in Poland in 2010, 2011, 2012, 2013 – Number of tenders [5]

	Type of procedure																			
Criteria	Competitive dialogue				Open procedure				Restricted procedure				Negotiated procedure without publication				Negotiated procedure			
Year	2010	2011	2012	2013	2010	2011	2012	2013	2010	2011	2012	2013	2010	2011	2012	2013	2010	2011	2012	2013
The most economic tender	0	9	40	41	281	354	476	615	29	19	43	113					46	31	56	22
Lowest price		1			3313	3599	3811	4124	286	210	213	212	33	33	34	69	10	14	15	7
Not specified					10	11	30	11	3	25		4	18	67	84	144		3	2	3

T a b l e 2

Percentage of contract award criteria in two types of procedures in Poland

Criteria	Open procedure				Restricted procedure			
Year	2010	2011	2012	2013	2010	2011	2012	2013
The most economic tender	7.8%	8.9%	11.0%	13.0%	91.0%	7.1%	16.8%	34.3%
Lowest price	91.9%	90.8%	88.3%	86.0%	90.0%	83.0%	83.2%	64.4%
Not specified	0.3%	0.3%	0.7%	0.2%	0.9%	9.9%	0.0%	1.2%

2.2. Germany

German procurement process procedures are laid down in VOB (*Vergabe-und Vertragsordnung für Bauleistungen* – German construction contract procedures) [6].

First publication of this act appeared in 1926 and it has been re-edited several times since then. The rules governing the process of awarding contracts are included in part VOB/A. In order to ensure compliance with VOB with the EU legislation, directives 2004/18/EC and 2004/17/EC were implemented in VOB/A in May 2006. VOB/A specifies the procedure for appointing contractors by means of considering the price and other criteria in relation to the object of the contract. Moreover, VOB/A defines the criteria of the contractors pre-qualification.

Table 3 shows that between 2010 and 2013 the majority of procurement processes in Germany took the form of an open procedure (92.1%). Other processes occurred as follows: restricted procedure – 1.8%, competitive dialogue – 0.1%, negotiated procedure with prior publication – 5.1% and negotiated procedure without publication – 0.9%.

In the open tender procedures the price was the only applied criterion in 56.8% of proceedings, and the most economically advantageous tender was chosen in 40.7% of all cases. Restricted tenders showed the 'lowest price' criterion to be pivotal in only 35.7%.

It is noticeable (Table 4) that the number of open and restricted tender procedures based strictly on the price criterion is increasing year after year, while the number of the tender procedures based on the most economically advantageous tender consistently decline.

2.3. UK

The Public Contracts Regulations SI 2006 No. 5 [7] are the set of rules governing the contract procurement process for works, services and supplies in Great Britain, Wales and Northern Ireland and came into force on 31st January 2006 preceded by an implementation of the EU directive.

Article 30 of the Regulations defines criteria for the award of a public contract and appointing the contractor. Similar to other countries, 'the most economically advantageous tender' (MEAT) or the lowest price tender has precedence over other criteria. The contracting authority specifies in the Specification the criteria for evaluating the tender offers. Criteria is strictly related to the object of the contract and need to be determined by its weighting (given to each criterion) [7] or should the contracting authority be unable to determine the weighting of the criteria, the criteria need to be marked in descending order from the most to the least important one. Furthermore, the criteria may have 'sub-criteria', e.g. the criterion 'cost' – 40% the sub-criterion is 'the contract value' – 20%, 'contract management' – 10%, 'consultants' – 10%.

Table 3

Selection criteria for appointing the contractors in Germany in 2010, 2011, 2012, 2013 – Number of tenders [5]

	Type of procedure																			
Criteria	Competitive dialogue				Open procedure				Restricted procedure				Negotiated procedure without publication				Negotiated procedure			
Year	2010	2011	2012	2013	2010	2011	2012	2013	2010	2011	2012	2013	2010	2011	2012	2013	2010	2011	2012	2013
The most economic tender	6	10	12	9	5355	4972	4372	4158	108	103	123	107	52	75	84	89	514	543	563	507
Lowest price					6143	6296	6616	7237	76	55	90	105	7	12	5	12	82	70	70	58
Not specified	2				308	302	272	303	23	53	58	12	21	35	42	41	31	61	49	21

Table 4

Percentage of contract award criteria in two types of procedures in Germany

Criteria	Open procedure				Restricted procedure			
Year	2010	2011	2012	2013	2010	2011	2012	2013
The most economic tender	45,4%	43.0%	38.8%	35.5%	52.2%	48.8%	45.4%	47.8%
Lowest price	52.0%	54.4%	58.8%	61.9%	36.7%	26.1%	33.2%	46.9%
Not specified	2.6%	2.6%	2.4%	2.6%	11.1%	25.1%	21.4%	5.3%

Table 5 shows that between 2010 and 2013 in UK the majority of procurement processes took the form of a restricted procedure (66.1%). Other processes occurred as follows: open procedure – 14.5%, competitive dialogue – 8.9%, negotiated procedure with prior publication – 9.7% and negotiated procedure without publication – 0.8%.

In the open tender procedures the price occurred as the only applied criterion in only 9.8 % of proceedings, and the most economically advantageous tender was chosen in 87.3% of cases. Restricted tender proved to be similar and showed the 'lowest price' criterion to be pivotal in 6.7%.

2.4. France

Public Procurement Regulations in France (Code des marchés publics) implemented the rules of the EU directive and adopted them in the decree no. 2006-975 of 1st August 2006 (Décret n°2006-975 du 1 août 2006 [8]). Article 53 of the decree outlines the criteria used by contracting authorities while conducting the procurement process. The criteria comply with their equivalents defined by the EU directive 2004/18/EC. The act also allows for the application of only one criterion which is price. Usually, the weighting of a criterion is the first element taken into consideration, e.g. technical value – 50%, price – 40%, innovation – 10%. In a situation where the contracting authorities are unable to determine the weighting of individual criteria, it needs to be described and organised according to their descending order of importance. The tender offer is evaluated in relation to all initially set criteria and an overall rate is given to the tenders that best meet the criteria. In case the price is constituted to be the only criterion, contracting authorities need to take the overall cost, e.g. including amortization, servicing, etc into account.

In accordance with the article 52 and decree no. 0039 of 15th February 2012 (JORF – *Journal officiel de la République française* n°0039 du 15 février 2012 – In the Official Journal of the Republic of France) [9] responsible for the Public Procurement Code of Conduct, the contractor must not be prevented from tendering for works due to the lack of their ongoing operation and performance within the area of works similar to the subject of the contract. However, the contracting authorities are responsible for determining a contractor's suitability.

Article 87 outlines the element of support given to small and medium-sized enterprises and creates the opportunity of requesting an advanced payment of up to 5% of the contract value, if the value of the tendered works is higher than 50 000€ and the time of accomplishment exceeds two months. Such support has not been proposed by the legislation of any other discussed countries.

Table 5

Selection criteria for appointing the contractors in UK in 2010, 2011, 2012, 2013 – Number of tenders [5]

	Type of procedure																			
Criteria	Competitive dialogue				Open procedure				Restricted procedure				Negotiated procedure without publication				Negotiated procedure			
Year	2010	2011	2012	2013	2010	2011	2012	2013	2010	2011	2012	2013	2010	2011	2012	2013	2010	2011	2012	2013
The most economic tender	186	165	161	136	198	196	227	321	1245	1117	1038	1107	2	2	6	7	164	179	201	158
Lowest price		2			19	19	33	36	112	83	55	82		2	3		2	2	6	6
Not specified	1	1	5		6	9	10	5	20	26	37		6	9	18	6	1	2	3	

Table 6

Selection criteria for appointing the contractors in France in 2010, 2011, 2012, 2013 – Number of tenders [5]

	Type of procedure																			
Criteria	Competitive dialogue				Open procedure				Restricted procedure				Negotiated procedure without publication				Negotiated procedure			
Year	2010	2011	2012	2013	2010	2011	2012	2013	2010	2011	2012	2013	2010	2011	2012	2013	2010	2011	2012	2013
The most economic tender	135	133	107	113	7760	8157	7632	7740	656	601	552	524	27	21	14	10	727	726	828	794
Lowest price					249	282	241	235	50	30	25	17	34	38	19	24	199	171	154	118
Not specified	5	14	16	13	453	524	564	535	64	99	82	59	6	5	5	6	151	169	216	150

Table 6 shows that between 2010 and 2013 in France the majority of procurement processes took the form of an open procedure (81.2%). Other processes occurred as follows: restricted procedure – 6.5%, competitive dialogue – 1.3%, negotiated procedure with prior publication – 10.5% and negotiated procedure without publication – 0.5%.

In open tender procedures price occurred as the only applied criterion in only 3.0% of proceedings, and the most economically advantageous tender was chosen in 91.0% of cases. In restricted tenders, the tendency proved to be similar and showed the 'lowest price' criterion to be pivotal in 4.3%.

3. Conclusions

The process of selecting the most competitive tender offer and appointing the most suitable contractor for the construction works is a complicated and risk-related task. Growing awareness of the importance of this process is increasingly more apparent between the parties involved in public procurement processes in the EU. Nowadays, public contracting authorities realise more often that a selection based strictly on appointing a contractor offering the lowest price may lead to a failure of the project.

The correct appointment of a competent and suitable contractor may have a positive impact on the outcomes of the works and result in: lowering construction cost, increased quality of delivered works, shortening of the works realisation time, higher number of qualified and competent workers, increased safety and lower number of accidents.

The analysis proves that procedures adopted in Germany, France and the UK complies with the UE directives. The examples from France and the UK show that the tendering processes in these countries are based on the award criterion of the most economically advantageous tender (MEAT). The German tendering process is more equal – almost half of all tenders are awarded based on MEAT criterion, and the rest is selected based on the lowest price.

Poland is the opposite with price as the only applied criterion in around 90% of the open tender proceedings. However, results of the analysis of the process in Poland between 2010 and 2013 prove that the number of the open and restricted tender procedures, based strictly on the price criterion is declining gradually year after year; while the number of the tender procedures based on the most economically advantageous tender consistently increases. The trend may have appeared due to the fact that the contract authorities began to realise the benefits emerging as a result of applying the non-price criteria in the process of the evaluation of offers.

It is very important that the selection of the assessment criteria is based upon individual elements of the offers and related to the specifics of the subject of contract.

References

[1] Directive 2004/17/EC of the European Parliament and of the Council of 31 March 2004 coordinating the procurement procedures of entities operating in the water, energy, transport and postal services sectors (OJ L134, 30.04.2004).

[2] Directive 2004/18/EC of the European Parliament and of the Council of 31 March 2004 on the coordination of procedures for the award of public works contracts, public supply contracts and public service contracts (OJ L134 30.04.2004).

[3] Commission Regulation (EC) No. 213/2008 of 28 November 2007 amending Regulation (EC) No 2195/2002 of the European Parliament and of the Council on the Common Procurement Vocabulary (CPV) and Directives 2004/17/EC and 2004/18/EC of the European Parliament and of the Council on public procurement procedures, as regards the revision of the CPV.

[4] Ustawa z dnia 29 stycznia 2004 r. Prawo Zamówień Publicznych (Dz.U. Nr 19, poz. 177, z późn. zm.).

[5] http//ted.europa.eu

[6] VOB-Vergabe-und Vertragsordnung fuer Bauleistungen, Teil A, Deutscher Taschenbuch Verlag, 30, Auflage 2013.

[7] The Public Contracts Regulations, SI 2006 No. 5.

[8] Décret n°2006-975 du 1 août 2006.

[9] JORF n°0039 du 15 février 2012 page 2600 texte n° 16 CIRCULAIRE Circulaire du 14 février 2012 relative au Guide de bonnes pratiques en matière de marchés publics NOR: EFIM1201512C.

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JAROSŁAW GÓRECKI*

PROBLEMS ACCOSSIATED WITH PROJECT MATURITY IN CONSTRUCTION COMPANIES

DOJRZAŁOŚĆ PROJEKTOWA PRZEDSIĘBIORSTW BUDOWLANYCH

A b s t r a c t

This paper describes the problem of project maturity for construction companies when analyzed by their ability to execute construction investment projects. On the basis of survey results it was revealed that the success of a company is connected with the increasing level of project maturity as a condition for a successful project management.

Keywords: project maturity, construction companies, risk management

S t r e s z c z e n i e

Artykuł dotyczy dojrzałości projektowej przedsiębiorstw budowlanych. Przeanalizowano je pod kątem zdolności do realizowania projektów inwestycyjno-budowlanych. Na podstawie wyników badań wskazano, że sukces przedsiębiorstwa budowlanego jest związany z podnoszeniem poziomu dojrzałości projektowej, warunkującej skuteczne zarządzanie projektami.

Słowa kluczowe: dojrzałość projektowa, przedsiębiorstwo budowlane, zarządzanie ryzykiem

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1. Introduction

The construction industry is a unique industry which evokes a necessity for paying special attention to various financial attributes and constraints varying in origin. The constraints, no matter if we call them The Iron Triangle [3], The Golden Triangle [13], or more accurately – The Project Management Triangle [22, p. 8; 21, p. 22; 9] or more complex – The Project Management Diamond [8, p. 471] or even one of the many other names we can use for the concept based on six or more variables, i.a.: scope, schedule, budget, risk, resources, quality, they always become the crucial features of a project. It is therefore obvious that any specific project will always end up being influence by such constraints, therefore a project manager needs to be focused on them. It has to be said that the project team must be able to assess the situation and balance demands in order to ensure the successful outcome of the project [23, p. 7]. Construction investment projects are basically the investment of money in order to create new or additional assets which a company intends to convert into further assets to provider future benefits. Risk, which is in fact a definition of the situation mentioned above, is a key factor affecting the success of the project [5, p. 18-27]. According to some studies [4], there is a specific relationship between the success of a project and the success of an enterprise. Moreover, it was revealed that there is a connection between the success of construction enterprises and their successful investment-construction projects [14, p. 278-285]. In general, however, they create a risk (as previously noted) in achieving two main objectives (schedule and budget) which can cause conflicts between owners and contractors which can lead to claims [12, pp. 20-29]. A response to the need for eliminating uncertainties and reducing risks coming from economic activity is an attempt to improve project management capabilities. For this reason construction companies need to pay more attention to the phenomenon known as project maturity.

2. Maturity of construction project management in polish construction companies

Before project maturity can be listed as a major factor, we must first understand what it means. In fact, maturity can be defined as the quality or state of being mature. If the concept of maturity is applied to an organisation it may refer to a state where an organisation is in a perfect condition to achieve its objectives. Consequently, project maturity can mean that an organisation is perfectly conditioned to deal with its projects [2].

A narrower concept of project maturity has been presented by various scientists. For example, maturity of risk management in large-scale construction projects and therefore models based on this phenomenon can effectively help organizations to understand the level of current practice in terms of their capabilities in risk management, as well as their strengths and weaknesses towards future risk management practice, in order to take appropriate actions to improve their risk management performances [17]. According to Deloitte's report, "construction companies rate the maturity of construction project management relatively high, and therefore a great number of organisations are well prepared for worsening market conditions" [11]. In 2012 Deloitte's researchers examined every answer received from thirty nine polish construction companies operating countrywide. Those companies were classified by three factors: revenue generated in 2010 in PLN, capital origin and presence on the Warsaw Stock Exchange. A structure of the sample [11]: up to 150 million PLN: 36%, 150–500 million PLN: 46%, over 500 million PLN: 18%.

According to the report, the concept of maturity refers to the comparative level of advancement that an organization has regarding any given activity or sets of activities. Organizations with more fully-defined and actively used policies, standards, and practices are considered more mature than the others. All respondents indicated one out of five maturity levels described below for each knowledge area.

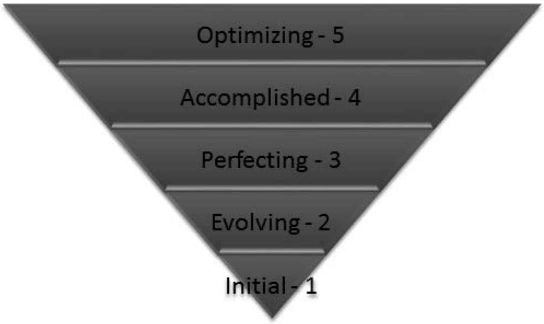

Fig. 1. Five maturity levels proposed by Deloitte (explanation below), source: own elaboration based on [11]

“1” (Initial) is a level featured by lack of standards or formal processes. “2” (Evolving) describes a level where some projects have developed best practice processes based on industry or consultant input and these processes are followed. However, processes are not routinely shared off project and are not been identified as standard. “3” (Perfecting) is a maturity level in which the organisation is developing its own best practice standards and centrally controlled project management processes. “4” (Accomplished) means that best practice process has been developed and rolled out across the organization. “5” (Optimizing) – the highest level of maturity – describes a best practice process which has been rolled out across the organisation and is being used on every applicable project. Project managers have a good understanding of the process, any problems that occur are resolved, and project feedback is provided on process improvement. In addition, the process has been optimized based on project feedback and knowledge of industry best practices [11].

It is worth underlining the fact that according to the Deloitte’s report, the overall result of the level of the construction project management maturity in Poland is 3,50. The indicator is calculated as a weighted average of values (namely maturity levels from 1 to 5) scaled by their importance (percentage of respondents selecting proper answer). Moreover, the indicator value of 3,50 implies that researched companies rate their project management maturity between a level of “Perfecting” and the level “Accomplished”.

The most reasonable conclusion of the survey results might be that companies try harder to develop their capabilities in terms of those areas that are officially introduced into law regulations. Occupational safety and health regulations, public procurement law, standardization like in particular quality standards (e.g. ISO) or some accounting regulations make companies to improve their current practice (procedures, behaviour etc.) and at the same time it gives them an opportunity todevelop their maturity in these areas.

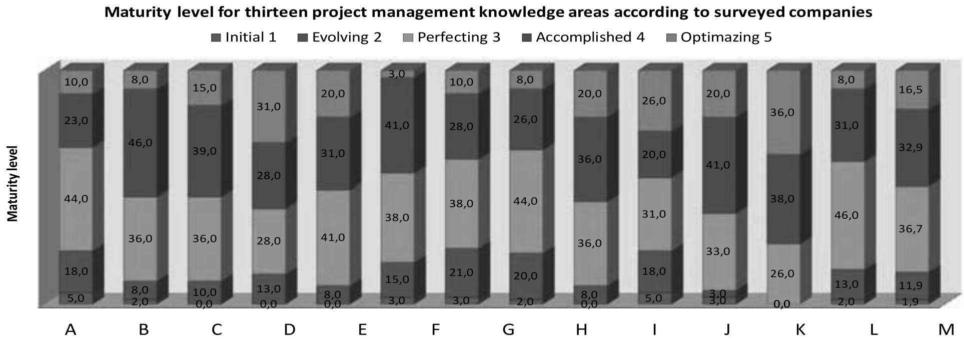

Fig. 2. Maturity levels for thirteen project management knowledge areas according to thirty nine polish construction companies (A – Project Integration Management, B – Project Scope Management, C – Project Time Management, D – Project Cost Management, E – Project Quality Management, F – Project Human Resource Management, G – Project Communication Management, H – Project Risk Management, I – Project Procurement Management, J – Project Environmental Management, K – Project Financial Management, L – Project Safety Management, M – Project Claim Management, N – Construction project management, overall scores), source: own elaboration based on [11]

3. Project maturity – is it really possible?

Literature review [10] recalls an explanation of the project maturity origins. A predecessor of this concept was process maturity created by the Total Quality Management movement. A need for process maturity resulted from efforts to reduce variability in the process and to improve its mean performance. Large-scale construction projects are practically always connected with risk factors which generally lead to adverse impacts and costly consequences in project management [17].

It is primarily worth noting that there is a difference between price risk (mainly connected with commodity [7] and arising out of adverse movements in the world prices, exchange rates and etc.) and cost risk which have technological and organizational origins. There are many definitions of cost risk which can be associated with a probability of loss due to cost overrun [6]. Investigation of this phenomenon and the factors affecting cost overruns for construction projects have attracted the interest of many researchers and practitioners [12]. More precisely, cost risk is the risk associated with the ability of the project to achieve the planned life-cycle costs. Thus, cost risk includes both design/construction and operating costs. John P. Kindinger and John L. Darby notice that there are two major elements of cost risk: the accuracy and completeness of the cost estimates for the planned activities and the risk that cost performance which will be affected adversely by a failure to manage technical risks, namely those events or issues associated with the scope definition, research and development (R&D), design, construction, and operation which could affect the actual level of performance vs. that specified in the project mission need and performance requirements documents [18]. Apart from price risk and cost risk, it is important to specify a variety of risk factors in construction projects. There are more crucial risks, such as time related risks [16, 19, 20, 24], quality related risks, design drawing errors, natural hazards and environment related risks [16, 19], safety related risks [1, 16, 19] as well as many others. In the following part of the article, some issues connected with human resource management and an impact of Generation Y on project maturity were also discussed.

4. Generation Y – chance or pitfall

Generation gaps between employees are a well-known problem [15]. But in the early 2000s, a brand new group of employees called Millennials (Millennial Generation, also known as Generation Y) became active on the labour market. This term was created in order to describe a group of people born from the early 1980s to the early 2000s. Whereas those dates are rather approximate, the phrase Generation Y first appeared in an August 1993 Ad Age editorial to describe teenagers of the day, which they defined as different from Generation X, and then aged 11 or younger as well as the teenagers of the upcoming ten years [27]. Since then, a phenomenon of Generation Y has attracted many sociologists and scientists carrying out research on the current problem connected with a suitability of the new group of employees in the organization. "Demography, not technology is creating the future" [25]. Some professionals maintain that Generation Y is not always an opportunity for the organization to build its competitive advantage but a kind of challenge. Millennials have been spoiled by their parents so probably they would feel appreciated if they were often rewarded for their efforts by employers [15, 26].

Moreover, it significant to employ the best candidates, to manage them and to retain successfully the most valuable Generation Y employees. To do so, managers should understand a sociological background affecting employees' behaviour.

5. Towards project maturity – own elaboration

A recent survey was conducted by the author in 2013 among 18 foreign construction companies. The sample was established after having sent an online questionnaire to 60 construction companies from abroad. All respondents were experienced in construction management and responsible for managing employees in their companies. None of these companies were classed as micro or small enterprises. The majority of them (50%) were described as large enterprise employing 250–999 employees. 33% were described as medium enterprise (50–249 employees). It is significant that 66% of the surveyed companies operated on the international market. Besides, respondents admitted that a business coverage can be described as regional (17%) or a national scale (17%). Among the companies that participated in the survey, none were present on the local or global market. The majority of the foreign construction companies in the survey stated that their main business activity area was in the construction of the roads (83%). The research presents the types of organizational structure implemented by surveyed companies. Whereas 33% respondents maintain their company has functional organizational structure, the same number of them answer there is a project organizational structure which is clear evidence of project manager awareness to create the right conditions for project management. Furthermore, a project organizational structure that was perceived in one-third of surveyed companies can prove that they are more project-matured that the others. Only 17% respondents answered that their company had no official certified management system. The rest of the possible choices could be multiple so 50% surveyed companies have both ISO 9000 and ISO 14 000 management systems. The majority of the companies are equipped with some project management software (67%).

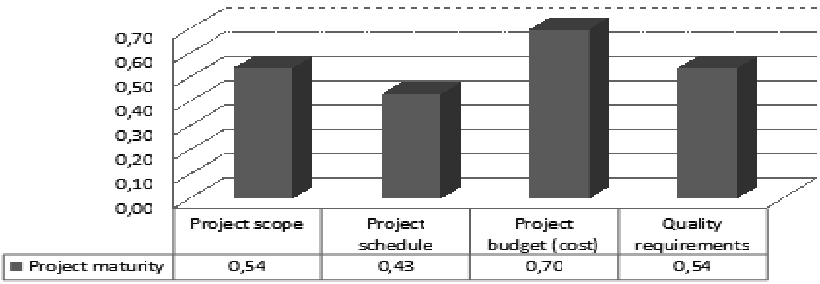

Fig. 3. Project maturity of the surveyed construction companies according to the respondents, source: own elaboration

In the figures above are results of project maturity calculations based on answers received and are represented by four different areas of project management. Organisations that decided to participate in the survey were requested to indicate an average probability of planned four main factors (project scope, project schedule, project budget and quality requirements) of the construction investment projects that have been executed by them. The concept of project maturity was created as a weighted average of values (namely an average probability of planned factors: 0.00–0.20, 0.21–0.40, 0.41–0.60, 0.61–0.80 and 0.81–1.00) scaled by their importance (number of respondents selecting proper answer). Moreover, the indicator value of 1,0 implies that researched companies rate their project management maturity as perfect (fully matured organization) whereas 0,0 means an organization is not project mature at all. Furthermore, there are three ranges of the indicator that classify three levels of project maturity: 0,00–0,33 – low level of project maturity, 0,33–0,66 – medium level of project maturity, 0,66–1,00 – high level of project maturity. Moreover, according to the survey, the overall score of project maturity among foreign construction companies was calculated as 0,55 (medium).

A perception (subjective interpretation) of respondents regarding project maturity of construction companies demonstrates that the majority maintain that their companies are quite matured (medium level – 33%) or matured (high level – 33%) in project management.

6. Conclusions

According to the results of the surveys presented in the article, it was revealed that both Polish and foreign companies appreciate the value of project management. They understand the importance of continuous improvements in project management capabilities.

On the basis of previous findings regarding project maturity, there is no doubt construction companies should try to improve their ability to manage projects.

The need for improving performance and perfecting risk management can be a good reason for creating a five-step model of continuous improvement of project maturity: 1. Planning ability, 2. Project management, 3. Maturity measurement, 4. Maturity evaluation, 5. Project maturity.

It might be a good solution for companies to engage in a constant pursuit of maturity. Indeed, it is a pursuit because as it was described previously, a fully matured organisation is just a theoretical concept.

Unfortunately, the survey did not touch a crucial issue – the aspect of Generation Y and their role in construction companies. Research into the role played by Gen-Y employees in the construction industry might be a good resolution for the future. Supposedly, as soon as modern managers of construction companies are able to profit from the skills of Generation Y, to employ and to retain the best of them, companies could reach a competitive advantage which would be enormously beneficial in today's turbulent economic environment.

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HYBRID APPROACH IN LEARNING FROM EXAMPLES IN CONSTRUCTION PROCESS DESIGN

PODEJŚCIE HYBRYDOWE W UCZENIU SIĘ Z PRZYKŁADÓW PRZY PROJEKTOWANIU PROCESÓW BUDOWLANYCH

Abstract

This paper presents options for implementing an advisory system to support production processes in the construction sector. With case-based reasoning methods (implementation of learning from examples) and simulation, an advisory system can be built on the foundation of a knowledge base, being a systematic collection of information aimed at the advancement of construction processes on site. Based on the evaluation of studied process results acquired in specified conditions (using the abductive approach), options are proposed for new case design engineering. The paper presents an example of application of case-based reasoning in delivering ready-mixed concrete to a large construction site from two batching plants.

Keywords: hybrid advisory system, flexibility, case-based reasoning, simulation, abductive approach

Streszczenie

W artykule zostaną zaprezentowane możliwości wykorzystania systemu doradczego wspomagającego projektowanie procesów produkcyjnych w budownictwie. Opierając się na metodzie *case-based* reasoning (wykorzystanie metody uczenia się z przykładów) oraz symulacji, można stworzyć system doradczy oparty na bazie wiedzy, która gromadzi systematycznie informacje dotyczące przebiegu procesów budowlanych na budowie. Na podstawie oceny rezultatów badanego procesu w określonych warunkach (wykorzystując podejście abdukcyjne) zostaną zaproponowane opcje projektowania nowego przypadku (new case). W artykule zostanie przedstawiony przykład zastosowania nauki z przykładów przy dostawie betonu towarowego na dużą budowę z dwóch węzłów.

Słowa kluczowe: hybrydowy system doradczy, elastyczność, case-based reasoning, symulacja, abdukcja

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1. Introduction

Construction is a unique industry, largely depending on numerous external factors. Variability of weather conditions, process participants, and the extensive range of community impact – these are examples of interruptions which can adversely affect the process of making technology decisions in construction process planning. Considering the major impact of external factors on project execution, the contractor will often be forced to withhold work or to continue working under increased risk of non-compliance with quality criteria and/or increased risk of financial losses.

When the various factors disrupting advancement of the production process are accounted for, designing construction processes will be approximated. Such an action will also facilitate the evaluation of considered alternatives (allowing flexible response to variable execution conditions) and to improve operating efficiency during project execution. It therefore seems reasonable to aim at the accumulation of knowledge and deployment of experience. Such undertakings provide the opportunity to execute construction processes according to the time and cost schedule, in compliance with applicable quality requirements.

The advisory systems contemplated in this article are based on the collection of knowledge. The practical implementation of knowledge from previous examples, one may estimate processes of performance and use it to find the optimum solution for the given problem. Therefore, advisory systems offer the opportunity to avoid disruption and mitigate problems. A key success factor is the implementation of a hybrid system, merging various methods functioning within the system, namely: analogy based on similarity of cyclical construction processes executed in similar conditions, abductive and deductive approaches focused on analyzing the causes of irregularities in the processes, and simulation modeling used to verify hypotheses generated through case analysis and later, the selection of production system parameters. The proposed methods will provide a synergy effect, offering an opportunity to achieve the anticipated results based on gradual improvements.

The purpose of this article is to present options for applying CBR (Case-Based Reasoning) and simulation in making production decisions in the construction sector.

2. Decision support systems in the construction

An important element of management activities in construction is to avoid working with exact figures (results of computations) but instead to work with solution generated options (as operating variants). In this process, it seems to be particularly important to use the knowledge gathered from various sources (rules derived from typical information sources, such as standards, recommendations, quality assurance system procedures, rules derived from reasoning during the decision support system operation, rules developed through application of specific tools/methods (ANN, CBR, MCDM, evolutionary algorithms, fuzzy logic, etc.). Considering the typical development path of a decision support system (meaning gradual evolution of a system dedicated to a specific application), one may identify the sequence of implementing various methods supporting decision-making during the particular stages:

1) Rules system (referring to typical expert systems).
2) Learning from examples (with optional application of simulation).
3) Machine learning (typically requiring collection of a huge volume of accurate data).

This article focuses on stage 2, in which foundations for application of simulation can be developed with knowledge gathered systematically on the basis of case analysis.

Special attention should be drawn to the implementation of multiple tools/methods in a single system, facilitating achievement of synergy between:
– various decision-maker support tools (e.g. between fuzzy rules and artificial neural networks [13], simulation and artificial neural networks [5, 12],
– capabilities of the user (and, preferably, the decision-maker being the same individual) and the advantages of information technology,
– development of decision-making skills (operational level management in the studied case) and implementation of these decisions in operating practice of the organization [16].

The above mentioned hybrid design of the system can also be defined according to the perspective by Zieliński [18] which distinguishes the following three essential stages of development:

Stage I. Calculation methods based on precise understanding of system dynamics;

Stage II. Expert systems based on deductive reasoning;

Stage III. Advisory systems based on inductive methods.

In this perspective, hybrid may be understood as the possibility of applying various methods appropriate for the three specified stages of decision support systems development.

Based on experience gathered over many decades (the first expert system was developed in the 1st half of the 1960s), one may point to several characteristics of DSS in early 21st century [1, 2, 10, 11]:
– use of all applicable means of communication to achieve on-line availability,
– accounting for interaction between representatives of multiple disciplines (technology, economy, sociology, ecology, etc.) focused on achieving a consensus despite often contradictory decision-making criteria,
– making decisions based on item life cycle analysis, implementing the idea of sustainable growth,
– using information from the monitoring of pending processes and the environment (with proposed increasing automation of the information gathering and data transmission process),
– assumptions of system user's professional background (previous assumption of user as layman encountered criticism) and system customization (dedicated to the specific decision maker).

To sum up, this a brief introduction into the idea of the application of advisory systems in construction, it would be advisable to point to certain problems with their implementation [17]:
1) problems with the representation and processing of knowledge in multiple disciplines (a manager in the construction sector is required to have interdisciplinary knowledge), involving a risk of contradicting interests,
2) explanations in expert systems are quite unique for specific circumstances,
3) need to consider the risk of operating outside the limits of proper system operation,
4) there are no systems capable of automatically learning from examples on operating level,
5) development of an expert system is very time-consuming.

The concept of the advisory system discussed is aimed at mitigating the problem listed above under (4). The proposal for automation is targeted rather on gathering information, data transmission and processing, assuming benefits from interactions between user and a computer with appropriate software (including solutions based on standard packages, such as spreadsheet with specialist add-ons). This approach facilitates user intervention with the objective of gradual system improvement by user/decision maker, not feasible in earlier systems (e.g. the GURU system featuring KGL language).

3. Monitoring

The following basic steps need to be taken for the purpose of planning reasonable construction process parameters:

– use of a knowledge base containing information of previous process executions,
– monitor the environment in order to evaluate and possibly record the data for the purposes of subsequent executions.

Monitoring the condition of the environment is a contributing factor for a more efficient response to dynamically changing conditions in the building process. It is realized through tracking and validation of processes, gathering and recording process information, and comparing the anticipated results with those achieved at the time of monitoring. A very important aspect of monitoring in construction is to observe and define the environment and account for the impact of these changes on deliverables. For a specialized contractor, obtaining and reporting progress information on processes, creation and implementation of databases are purposeful activities serving the purpose of improving the planning of construction process implementation.

Thus, monitoring constitutes the first stage of action in a hybrid learning system. The primary purpose of this system is to generate a knowledge base.

4. Case-Based Reasoning

A knowledge base is created during monitoring the environment of the given process in progress. It serves the purpose of accumulating information about the given processes and implementing experience in new cases. This knowledge will be based on the method of learning from examples.

Case-Based Reasoning is a method of resolving problems on the basis of equivalent prior cases. Therefore, CBR facilitates production process planning/engineering in new circumstances/cases due to:

– building a new solution on the basis of knowledge from prior cases [8],
– application of similar historical examples to explaning the new situation [14],
– application of historical cases for critical and objective review of the new case,
– drawing conclusions from documented cases to be able to interpret a new situation.

CBR method is acknowledged in many disciplines: in medical diagnostics, risk assessment, planning and design engineering. It may also be used in construction: during a production engineering process, cost estimation and creating quality management procedures. An example of learning from experience which is discussed in this article are the supplies of ready-mix concrete in a typical four-stage cycle. Learning from examples is based on systematic collection of data on the estimated performance of the concrete mix delivery process, which is a cyclical.

5. Abduction and deduction in CBR with simulation

In order to maximise benefits from the application of knowledge bases, application of an abductive and deductive approach is proposed. Abduction and deduction constitute to integral problem solving methods [9].

Abduction serves the purpose of explaining the causes of certain phenomena. In the algorithm of knowledge application in construction process management, it can be used for analyzing and determining the causes of any deviations that may occur. It should be emphasized that abduction is a reasoning system based on hypothesis. We are only trying to discern the causes of the occurring deviations. Therefore, identification of a potential cause of such deviations does not guarantee that the same solution can be applied again when another similar problem occurs. Example causes of prolonged driving time may include a road accident or fog. Abduction logic would present itself as follows:

1. P!
2. $\sim A(K, P)$
3. $\sim A(\mathrm{K}^*, P)$
4. $A^{pres}(K(H), P)$ (1)
5. H neets aditional criteria $S_1, ..., S_n$ (1)
6. Thus, $C(H)$
7. Thus H^c

In this diagram [4], P is the purpose, i.e. recognising the causes of disruption. It is not possible to achieve the purpose on the basis of existing resources (K base and its extension – K^*). The role of abduction is to create the hypothesis H which will facilitate realising the demand for "alleged perceivable availability" (on the condition of fulfillment of certain additional criteria $S_1, ..., S_n$). It is therefore reasonable to consider the hypothesis (C(H)) and to accept it as appropriate (H^c).

On the other hand, deduction involves drawing conclusions. With reference to the example in hand, the role of the deductive approach is to use gathered information in practice and make a logical choice of the solution which seems most beneficial in the specific conditions on site. To enhance the ability for making the right decisions, it would be substantiated to use knowledge acquired through experience as a way to determine the most approximate case (CBR abduction and deduction). Such cases will in turn help in finding a reasonable solution in construction process designing.

The learning from example cycles based on abduction and deduction (Fig. 1) can be divided into two major parts: the first part involves the application of the abductive approach, the second – the deductive approach. During the execution of a construction process, while monitoring any disruptions and preparing a final report, detailed analysis of the causes of disruptions is carried out and unnecessary process steps are eliminated (Lean Management). Simulation is used for resolving this problem through abduction, for the purpose of the adequate modelling of various anomalies in the process at hand. Use of experience (CBR abduction) provides systematic process improvement through building a process model without interruptions (case net) for various adverse circumstances. Historical case processing will be used as the basis for designing production processes in subsequent repeated cycles – consecutive new cases (CBR deduction). The cycle of learning from examples, both in its abductive and deductive phase, can be supported by simulation methods discussed below.

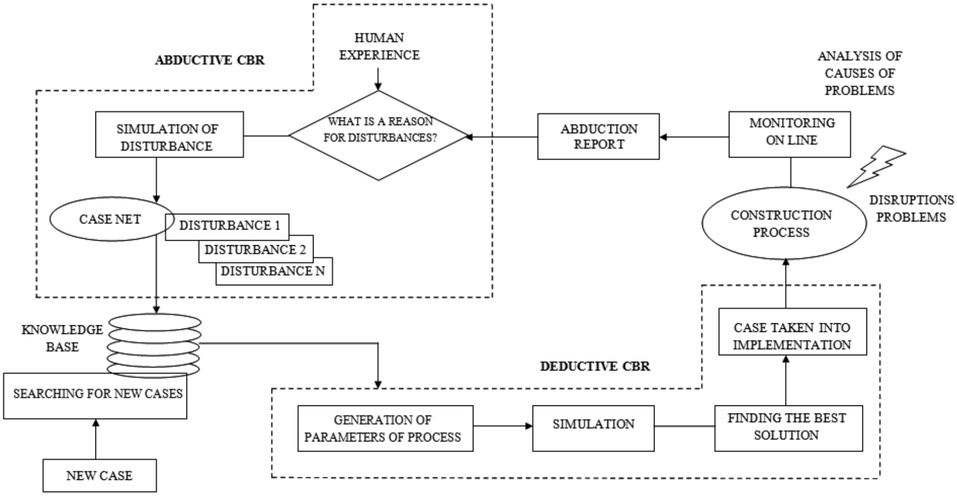

Fig. 1. An idea of abductive and deductive CBR approach by simulation

Its main advantage is the possibility of modelling the actual state without incurring significant costs. According to Fig. 1, simulation in the process in hand can be applied in two instances. The first is the application of simulations during a construction process in which disruptions may occur. Assuming certain types of statistical distributions for the given process, we may model the process to present the net case. The second stage is the application of a simulation system with a deductive approach in order to choose process parameters in new case analysis. With the use of experience from similar construction processes together with simulation techniques, the described process can be perfected.

6. Case study – fresh concrete delivery

An example of employing knowledge obtained from previous cases discussed in the article is the delivery of ready-mixed concrete. The following stages can be distinguished within the concrete delivery cycle: loading the truck mixer, transport to site, concrete mix testing (in case of nonconformity, the batch will be returned to batching plant), unloading (when pump busy, truck mixer waits in queue for unloading), washing (and possible queuing), return to batch production plant. (Fig. 2). The random character of loading, delivery and placement of the concrete mix generates truck mixer downtimes (typically, batching plant and pumps are considered the leading machines).

In order to find a similar case to facilitate the concrete process, first you have to define the process settings. Graham and Smith [6] quote these five main factors: type of concreted item, month, weather, concrete volume, number of truck mixers to deliver the concrete mix. According to Dunlop and Smith [3], other factors with a significant influence on concreting capacity include: the distance between the batching plant and the construction site, truck mixer capacity, pump capacity, pump type and age.

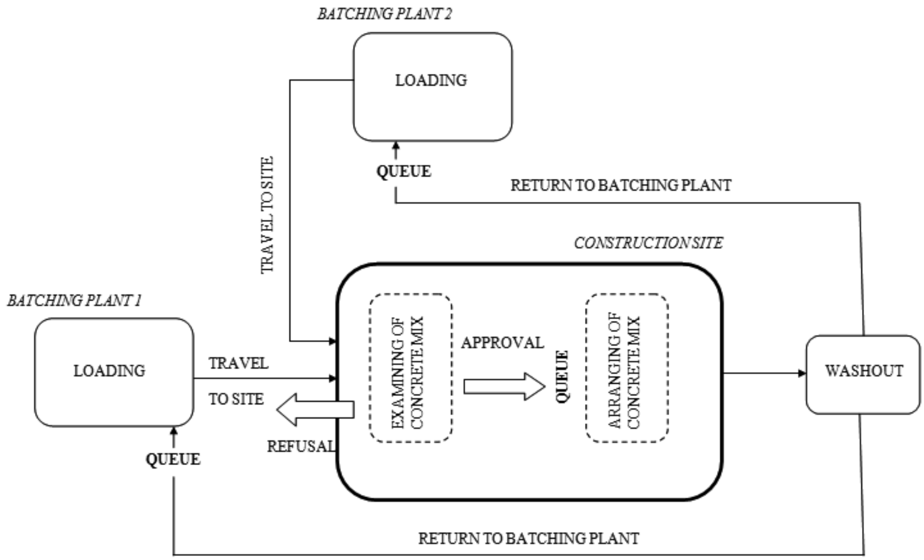

Fig. 2. Delivery of ready-mix concrete

The example discussed in this article is the delivery of concrete mix for the foundation slab of an office building erected in Poznań. The concrete mix was supplied from two batching plants, one in Dąbrowa 10.4 km away from the site and the other in Poznań, 9.3 km from the site. Nine 9 m^3 capacity truck mixers were used to carry the mix. Gathering cases in determination of process efficiency commenced with identification of criteria to describe the cases in the knowledge base:

1. Type of element (slab = SLA, wall = WAL, base plate = BAS, other = OTH) – represents a change of performance for specific shapes and dimensions of structural components;
2. Temperaturae (–15°C – EL, –14°C to –5°C – L, –4°C to – 0°C– HL, 1°C to 5°C – LM, 6°C to 15°C – M, 16°C to 25°C – MH, > 26°C – EH) – represents ambient temperature during transport and pouring of concrete mix;
3. Weather (sunny, cloudy, rainy, snowy, sunny spells) – weather conditions for delivery and placement of concrete mix. Subjective criteria, based on user's assessment;
4. Concrete volume (0–9, 10–19, 20–29, ..., 340–349, > 350 [m^3]) – volume of the structural component;
5. Truck mixer capacity (6–8 – L, 9–10 – M, 11–12 – H [m^3]) – rated capacity per truck mixer;
6. No. of truck mixers (1–5 – L, 6–10 – M, 11–15 – H, > 16 – EH [pcs.]) – number of truck mixers in circulation to carry the mix;
7. Travel time (6:01–9:00, 9:01–12:00, 12:01–15:00, 15:01–18:00, 18:01–6:00) – hours for transporting concrete mix.

With these criteria, a research form could be created to generate a process database. The database identifies causes of occurring disruptions (in the example given in table 1, these disruptions involved cement stuck in bin chute, causing several minutes of delay in loading).

Table 1

Data on concrete mix deliveries

No.	Arrival time to the batching plant	Time of the start of loading the concrete mix	Time of the end of loading the concrete mix	Departure time from batching plant	Type of disruptions	Tempe-rature	Weat-her	Abduction
1.	22.22	22.22	22.34	22.34	ok	m	ss	–
2.	22.33	22.35	22.47	22.47	ok	m	ov	–
3.	22.45	22.47	23.02	23.02	delay 15min	m	ov	wedged cement in the funnel
4.	22.57	23.03	23.15	23.15	ok	m	rn, ov	–
5.	23.09	23.10	23.22	23.22	ok	m	rn, ov	–

The data collected was then used for process simulation. Two types of software – FlexSim and WebCYCLONE – were used for executing the simulation. Simulation results from both applications were compared. The values of results differ slightly. Efficiency of the process discussed in the article was as follows: for the Dąbrowa batching plant – 26.56 [m^3/h], for the Poznań batching plant – 18.16 [m^3/h]. With given equipment rental cost data, further analysis involved a simulation, leading to the conclusion that with varying numbers of vehicles, it would be reasonable to use six truck mixers [7, 15]. With the application of knowledge from the case under review, another similar process can be improved and its costs will be reduced.

7. Conclusions

The options discussed for implementing an advisory system for planning concrete mix delivery processes on the basis of the abductive and deductive approach lead to the following conclusions:

1. It is possible to learn from examples in cyclical construction processes;
2. Gathering knowledge from examples is an interim phase in development of a hybrid advisory system, a hybrid of Rule Based Reasoning and Machine Learning. e.g. Artificial Neural Networks);
3. The proposed solution offers the possibility of implementing a mechanism for eliminating nonconformities with the use of abductive reasoning in combination with Lean Management;
4. With the use of simulation and learning from examples, a synergy effect can be achieved, increasing the efficiency in the implementation of the proposed system;
5. The search for an efficient solution allowing for analysis of the process in hand both in the optimum scenario (minimum disruption), most probable (normal) scenario and worst case scenario, which will ensure the preparation of appropriate resources for different situations;

6. At a relevant stage of development of the advisory system (more advanced visualisation than in the FlexSim package), training courses can also be held in the form of management games.

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DECISION MAKING WITH USE OF AHP METHOD IN CONSTRUCTION

PODEJMOWANIE DECYZJI W BUDOWNICTWIE Z WYKORZYSTANIEM METODY AHP

Abstract

One of the most difficult problems in construction having to take an objective decision, especially when selecting contractors. The decision making process is both complicated and time consuming (due to the complex nature of construction projects). Many experts, with extensive knowledge of the Construction Industry, take subjective decisions, related to verbal methods of decision making. The previously mentioned difficulties mainly relate to the creation of a relevant criteria set, answering the decision makers questions. A proper criteria set and mathematical tools (like computer calculation algorithms with multi-criteria analysis) could significantly improve objective decision making. The authors present a case study – selection of contractors – with detailed calculations of AHP method.

Keywords: informatics tool, multi criteria decision making, AHP, contractors choice, case study

Streszczenie

Jednym z najtrudniejszych problemów w budownictwie jest podejmowanie decyzji, zwłaszcza dobór odpowiednich wykonawców. Proces decyzyjny jest bardzo skomplikowany i czasochłonny (ze względu na złożony charakter projektów budowlanych). Wielu ekspertów, z rozległą wiedzą o budownictwie, podejmuje subiektywne decyzje, związane z werbalnymi metodami podejmowania decyzji. Trudności związane są głównie z doborem odpowiednich kryteriów, odpowiadających oczekiwaniom decydenta. Zestaw odpowiednich kryteriów i narzędzi matematycznych (takich jak komputerowe algorytmy obliczeniowe dla oceny wielokryterialnej) może znacznie usprawnić proces podejmowania decyzji. Autorzy przedstawili studium przypadku – wybór wykonawcy ze szczegółowymi obliczeniami w ramach metody AHP.

Słowa kluczowe: narzędzia informatyczne, kryteria podejmowania decyzji, AHP, wybór wykonawcy, studium przypadku

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1. Introduction

One of the main problems faced by every investor/project manager are decisions required regarding selection of the investment project implementation variant [13, 14]. The difficulty associated with this issue emerges as early as at the investment preparation stage, when the investors requirements and expectations of are defined in the functional and utility program. At individual stages during the life cycle of the undertaking, the phenomena analyzed are very complex, mainly due to the specific traits, characteristics, complexity and nature of construction processes and relations between them. On the other hand, a description of these relations, based mainly on expert opinions, should take into account factors which are both measurable and those which are difficult-to-measure [17], and its quality depends largely on the expert knowledge and experience of the decision-makers.

The issue of decision-making constitutes an integral part of every field of science and art. The decision-making process is an activity, which results in the making of a specific decision. For the entity of the decision-making process, the decision-maker is involved, expressing specific preferences, assessing, possibilities and results as well as choosing the final decision-making variant [2, 3, 5, 6, 10, 13–15]. Analyzing the decision-making situation is the first task of the decision-maker. The decision-making situation is a set of all elements, which are dependent and independent of the assessor, which exert an impact on the decision to be made. In the process of formulating the decision-making problem, the factors independent of the decision-maker include the set of variants being examined (the so-called conditions restricting the decision), while factors dependent upon the decision-maker include the criteria of the assessment of solutions, described by technical and economic indicators, most adequate for a given decision-making situation, expressed in specific units [2, 8–10, 15].

The assessment of variant characteristics may be both quantitative (objective) and qualitative (difficult to measure) [17]. The difficulty in decision-making is due not only to the level of complexity of the task and designation of the variants, but also the expectations of the person doing the assessing. On the other hand, the preferences of the expert are largely dependent upon the point of view of the decision-maker, who has caused the given opinion or assessment to develop. The authors believe that, due to the above reasons, computer-based implementation of calculation algorithms of the selected methods of assessment and ranging solutions is an efficient tool, allowing aggregated variant assessments to be obtained, making the decision-making process more efficient. Detailed information concerning the issues of the valuating criteria, as well as the psychological aspect of decision making have been presented in [1, 2, 10, 15]. An exemplary course of the decision-making process has been presented using the AHP method as an example [16].

2. The main assumptions of the methodology

According to the authors, calculation algorithms of various types of methods of multi-criteria assessment as well as theoretical apparatus, including sociological and psychological theories lay behind decision making. The decision-making analysis contributes to the greater effectiveness of the decision-making process help avoid substantial mistakes which could interfere with the quality and reliability of the decisions made. In practice, individual tools are often used selectively, which often garbles the assessment results. The experts are expected to make assessments in accordance with their professional knowledge and construction art – reliable, objective, taking the specific character of a given decision-making situation into account. It would be difficult, however, to clearly define individual preferences, systems of values and motivations of an expert. Expert opinions are formulated on the basis of their knowledge and experience and they depend upon such factors as availability of information and the level of complexity of the task, emotional state and mood, self-esteem and susceptibility to group influence as well as the perception of a given phenomenon [2, 10–12, 15]. In some cases, the difficulties associated with decision-making could be due to fear of assuming responsibility, making a mistake or being rejected by the community. In order to eliminate as many causes of interference associated with decisions to be made as possible, an original survey of decision-maker preferences has been developed, as well as a decision-making variant ranging procedure. The intention of the survey, developed within the framework of this research, in the opinion of the authors, was – in the first place – to clearly define and fine tune the assessment of variants, referring to the problem of selection of the best investment (e.g. premises, building) from the perspective of the expectations of potential recipients (users).

3. Definition of pre-qualification

Preliminary qualification is also called pre-qualification. Hatush and Skitmore [4] define pre-qualification as the process preceding the tender, used to examine and assess the contractor from a perspective of their capability to perform the contract successfully. This procedure is carried out on the basis of a set of preliminary qualification criteria. Thus, pre-qualification can be referred to as a selection of building contractors from the investor (or their proxy) on the basis of a subjective set of criteria, aimed at assessment of predispositions of the company to properly implement the construction project. In practice, this means that any contractor wishing to participate in the tender must first undergo the pre-qualification process. Two types of qualification procedure can be distinguished, which can also be applied as two of the stages of pre-qualification [7]: standing list and per project prequalification. Creation of a list of contractors able to perform specific types of projects (e.g. contractors having specialist equipment or specializing in performance of a given type of construction works). Such lists are created by public and private (large and small) investors. Only those companies included on the appropriate standing list are invited to participate in tenders for performance of specific types of works. A list of this kind needs to be updated at least once every two years and the group of contractors selected must be those most suitable for a given construction project; this form of qualification is more precise than the standing list, described above, and it is performed as necessary for a specific project. As a result, a short list of companies invited to tender is established.

4. Example of AHP method use – case study

During paired comparison (determination of key factors dominance) authors assumed grading scale suggested by Trzaskalik [16], based on Saaty solution (table 1). Hence grades entered in the matrix belong to the set: {1/9; 1/8; 1/7; 1/7; 1/5; ¼; 1/3; ½; 1; 2; 3; 4; 5; 6; 7; 8; 9}.

Table 1

Grade scale – pair-wise comparison (developed internally on the basis of [16])

Grade	Verbal judgments of preferences
1	Equally preferred
3	Moderately preferred (variant 1 better then variant 2)
5	Strongly preferred (variant 1 better then variant 2)
7	Very strongly preferred (variant 1 better then variant 2)
9	Extremely preferred (variant 1 better then variant 2)
2, 4, 6, 8	In-between assessments (variant 1 better then variant 2)
Reciprocal grades	Equivalent preference but variant 2 better then variant 1

Table 2

Average random consistency (RI) (developed internally on the basis of [16])

Size of matrix	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

In this case study three contractors (A, B, C) are being assessed on the basis of four criteria: experience, financial stability, reputation and organizational skills. Contractors properties were assessed by experts (shown in Tab. 3). The following Tab. 4, 5, Fig. 1, 2 and formulas 1, 2, 3 show calculations for first criteria – experience. There is a need to prepare similar calculations separately for all selected criteria. So the first step of the procedure is to develop a set of comparison matrices. The pair-wise comparison should be made by qualified experts. Then, a synthesized matrix is created. This is achieved by dividing the relevant fields in the comparison matrix by the sum of values in the proper column. For example field AA = 0.652 was calculated as division of field AA of comparison matrix (table 4) = 1 by value of 1.533 (1.533 = 1 + 1/5 + 1/3). Priority vector is obtained by calculating average values of fields in synthesized matrix rows (Tab. 5). For example, for A row it is (0.652 + 0.625 + 0.667)/3 = 0.648.

Table 3

Contractors properties – criteria (own study)

	Contractor A	Contractor B	Contractor C
Experience	4 years on the market 3 similar projects	8 years on the market none similar projects	7 years on the market 1 similar projects
Financial stability	Average	Very good	Very good
Reputation	Excellent	Very good	Good
Organizational skills	Good	Very good	Average

Table 4

Comparison matrix – Experience assessment (bold lines) (own study)

Experience	A	B	C
A	1	5	3
B	1/5	1	1/2
C	1/3	2	1
Σ	1.533	8.000	4.500

Table 5

Synthesized matrix – Experience assessment (bold lines) (own study)

Experience	A	B	C	priority vector
A	0.652	0.625	0.667	0.648
B	0.130	0.125	0.111	0.122
C	0.217	0.250	0.222	0.230
				Σ = 1.000

The next step is to calculate maximum eigenvalue λ_{max}. To do so, a weighted sum matrix (Fig. 1) is created by multiplying the comparison matrix by the priority vector. Then the results are divided by the relevant elements of the priority vector (Fig. 2).

$$0.648\begin{bmatrix}1\\1/5\\1/3\end{bmatrix} + 0.122\begin{bmatrix}5\\1\\2\end{bmatrix} + 0.230\begin{bmatrix}3\\1/2\\1\end{bmatrix} = \begin{bmatrix}1.948\\0.367\\0.690\end{bmatrix}$$

Fig. 1. Weighted sum matrix (own study)

$$\frac{1.948}{0.648} = 3.007\ , \quad \frac{0.367}{0.122} = 3.001\ , \quad \frac{0.690}{0.230} = 3.003$$

Fig. 2. Elements of weighted sum matrix divided by relevant elements of priority vector (own study)

The maximum eigenvalue for criteria – experience is the average of calculated values (formula 1). Consistency index *CI* is calculated on the base of formula 2, where n is the number of contractors. For $n = 3$, random consistency $RI = 0.58$. which is why the consistency ratio *CR* is derived from formula 3 (requested condition was fulfilled – comparison consistent).

$$\lambda_{max} = \frac{3.007 + 3.001 + 3.003}{3} = 3.004; ; \quad (1)$$

$$CI = \frac{\ddot{e}_{max} - n}{n-1} = \frac{3.004 - 3}{3-1} = 0.00185 \quad (2)$$

$$CR = \frac{CI}{RI} = \frac{0.00185}{0.58} = 0.003187 < 0,1 \quad (3)$$

After calculations for all criteria it is necessary to follow the same calculations for all sets of criteria. The experts task is to compare all of the criteria – experience, financial stability, reputation and organizational skills.

Table 6

Comparison matrix – All criteria comparison (bold lines) (own study)

Criteria	Exp.	Fin. Stab.	Rep.	Org. Sk.
Experience	1	1/2	1/4	1/7
Financial Stability	2	1	1/2	1/5
Reputation	4	2	1	1/3
Organisational Skills	7	5	3	1
Σ	14.000	8.500	4.750	1.676

Table 7

Synthesized matrix – All criteria comparison (bold lines) (own study)

Criteria	Exp.	Fin. Stab.	Rep.	Org. Sk.	Priority Vector
Experience	0.071	0.059	0.053	0.085	0.067
Financial Stability	0.143	0.118	0.105	0.119	0.121
Reputation	0.286	0.235	0.211	0.199	0.233
Organisational Skills	0.500	0.588	0.632	0.597	0.579
					Σ = 1.000

Then, maximum eigenvalue is calculated (Fig. 3) for all criteria in the same manner as presented on Fig. 1, 2 and in formula 1.

The consistency index *CI* is calculated for all criteria on the basis of formula 4, where n is a number of criteria. For $n = 4$, random consistency $RI = 0.90$. which is why the consistency ratio *CR* is derived from formula 5 (requested condition being fulfilled – comparison consistent). The final step of the procedure is to calculate the overall priorities of each contractor and then create their ranking (hierarchy of contractors).

$$0.067\begin{vmatrix}1\\2\\4\\7\end{vmatrix}+0.121\begin{vmatrix}1/2\\1\\2\\5\end{vmatrix}+0.233\begin{vmatrix}1/4\\1/2\\1\\3\end{vmatrix}+0.579\begin{vmatrix}1/7\\1/5\\1/3\\1\end{vmatrix}=\begin{vmatrix}0.269\\0.487\\0.936\\2.352\end{vmatrix}$$

$$\frac{0.269}{0.067}=4.006,\quad \frac{0.487}{0.121}=4.019,\quad \frac{0.936}{0.233}=4.025,\quad \frac{2.352}{0.569}=4.062$$

$$\lambda_{\max}=\frac{4.006+4.016+4.025+4.062}{4}=4.028$$

Fig. 3. Maximum eigenvalue for all criteria – calculations (own study)

$$CI=\frac{\lambda_{\max}-n}{n-1}=\frac{4.028-4}{4-1}=0.00946 \tag{4}$$

$$CR=\frac{CI}{RI}=\frac{0.00946}{0.90}=0.010506<0.1 \tag{5}$$

The overall priority is calculated as show on Fig. 4 (values from criteria comparison priority vector – from Table 7 – are given without brackets and values from priority vectors for each criteria – in brackets).

Overall priority for Contractor A = 0,067·(0,648) + 0,121·(0,077) + 0,233·(0,557) + 0,579·(0,234) = 0,318
Overall priority for Contractor B = 0,067·(0,122) + 0,121·(0,462) + 0,233·(0,320) + 0,579·(0,688) = 0,537
Overall priority for Contractor C = 0,067·(0,230) + 0,121·(0,462) + 0,233·(0,123) + 0,579·(0,078) = 0,145

Fig. 4. Maximum eigenvalue for all criteria – calculations (own study)

Calculations show, that Contractor B is the best one, according to chosen criteria.

5. Conclusions

Mathematical and thus objective methods that support the decision-making process in construction undoubtedly help the everyday work of a construction manager. The AHP method allows an optimum solution to be selected among defined alternatives (evaluation problem) or in the identification of a preferred alternative among the potentially infinite, suggested set of alternatives, defined from the perspective of the set of restrictions (design problem). This support of the decision-making processes provides many advantages:

- allowing the decision-making process to be viewed from a different perspective, by ordering the criteria and variants within the framework of the established hierarchy;
- reduces the multi-criteria problem to a number of simple comparisons in pairs of individual criteria and variants within the framework of the established hierarchy;
- provides the possibility of joint analysis of measurable and non-measurable criteria and obtaining an aggregated assessment of variants;
- eliminates the risk of a decision being influenced by bias and manipulation;
- allows for the analysis of sensitivity (impact of changes of individual unit assessments upon the final decision).

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WAYS TO DETERMINE CRITERIA IN MULTI-CRITERIA METHODS APPLIED TO ASSESSMENT OF VARIANTS OF A PLANNED BUILDING INVESTMENT

SPOSOBY OKREŚLANIA KRYTERIÓW W WIELOKRYTERIALNYCH METODACH OCENY WARIANTÓW PLANOWANEJ INWESTYCJI BUDOWLANEJ

A b s t r a c t

When planning a construction investment, an evaluation is often performed. In order to make the best possible choice, it is necessary to define the correct specification of the evaluation criteria which will guide us through the decision-supporting procedure. Some criteria refer to measurable phenomena, hence they can easily be defined. Others, however, need to be described with linguistic methods and require adequate scale and identification methods. This article presents methods used to prepare and choose the correct criteria for carrying out an assessment of the building investment, applicable to various criteria and different multi-criteria methods.

Keywords: building investment, multi-criteria methods

S t r e s z c z e n i e

Na etapie planowania inwestycji budowlanych często przeprowadzana jest ocena wariantów ich realizacji. Aby dokonać optymalnego wyboru, należy właściwie określić kryteria oceny, którymi będziemy się kierować, przeprowadzając procedurę wspomagania wyboru. Niektóre kryteria dotyczą zjawisk mierzalnych i są łatwe do definiowania i wagowania. Inne natomiast wymagają opisu metodami lingwistycznymi, ustalenia właściwej skali i odpowiednich metod ich identyfikacji. W artykule zaprezentowano metody właściwego doboru kryteriów oceny wariantów inwestycji budowlanej dla różnych kryteriów i różnych metod analizy.

Słowa kluczowe: inwestycje budowlane, analiza wielokryterialna

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1. Introduction

A decision is when a decision-maker wishes to make a change to the existing situation. Each decision comprises some elements of randomness and its economic, social, organizational and market consequences are not easy to predict. In practice, a decision-making process focuses on analyzing alternatives which – to a greater or lesser extent – fulfill the set of desired goals. Thus, a decision means choosing one of these options. In the construction industry, decisions are made and alternatives chosen at the stage of planning a building investment and selecting a variant solution [1, 4]. When analyzing all executable variants, we deal with a series of criteria regarding the location, impact on the environment, construction solutions, costs and benefits, social and economic costs, etc.

In order to solve multi-criteria problems [6], we often try to capture our expectations with the aid of a single criterion which aggregates all significant consequences related to the problem. If that is the case, we face the task of performing a single-criterion analysis, in which each potential variant is valued against an a *priori* chosen criterion, e.g. costs, inputs, time of execution, profit, rate of return, benefits. The following are used to solve the type of problems listed above using: linear programming methods, parametric programming, target programming, margin analysis, stochastic programming, non-linear programming, etc. Although this approach can only be justified in some *albeit* very simple cases, using a single-criterion reference cannot be recommended for complex investment processes, being not completely reliable and lacking the properties that would enable the presentation and analysis of the whole spectrum of questions and problems connected with the process of planning and preparing building constructions. A multi-criterion decision-making process, unlike a single-criterion analysis, enables one to express a cohesive family of criteria as an instrument of full and exhaustive communication, which should facilitate the formation, justification and transformation of preferences during the decision-making process.

2. Characteristics of a criteria's variety in the multi-criterial analysis

Multi-criteria decision supporting requires the participation of many individuals, who are experts providing their opinions on specific topics [6, 7]. Expert opinions are the basis for determining the criteria which will be significant for further steps in the decision-making process. Typically, experts express different viewpoints, which are the result of their different perception of the reality and process which are taking place in real world. This diversity of opinions presented by specialists is also due to the different functions they play in the investment process. This is why both the assessment and its final outcome can be burdened by some error, which should be kept in mind. Subjectivity can mainly be encountered when applying methods which include the analysis of quality-type factors. When so-called 'measurable factors' are assessed, the result of an assessment against a given criterion are obvious. Two methods for obtaining an objective assessment of quality-type factors can be considered. One is a descriptive evaluation of the importance of a criterion. The other one requires adopting a numerical measurement scale. Non-measurable factors often appear when planning an investment project. They can be taken into consideration in such multi-criteria methods as the MCE analysis, the AHP analysis or indicator methods. However, the final results of these analysis can be difficult to evaluate.

The MUAT (Multi Attribute Utility Theory) method is frequently used to analyze the effects a development project may have on the environment. It relies on two assumptions. Firstly, there is often incomplete input data regarding the natural environment around the site where a building investment will be located. Second, the person who performs an environmental impact analysis is under pressure to hide ongoing events and their consequences, whose occurrence is uncertain and difficult to predict [4, 6, 8]. The first step in an analysis carried out according to the MUAT method is to determine the measurable parameters of the natural environment at the site of a future construction object, such as the level of noise, exhaust fumes, surface water pollutants, etc. The characteristics chosen for the analysis are those which enable a quantitative evaluation of the state of the environment. There may be various measures or states for each type of impact, which can be calculated with the aid of forecasts or models worked out from multi-year monitoring procedures. The second stage is to express the utility function $U(x)$ on a 0–1 scale, where 0 means the least utility and 1 stands for the highest utility. Once utility functions $U_i(x_i)$ are determined for individual characteristics of the environment, it is possible to present mutual connections by determining weights or scaled values for each parameter describing the natural surroundings. Scaled values are a reflection of the relative value in which decision-makers perceive different attributes. The total utility or a complex index of the quality of the analyzed natural environment ***WJ*** can be derived from the formula:

$$\boldsymbol{WJ} = U(x) = \sum_{i-1}^{n} K_i \cdot U_i(x_i) \tag{1}$$

where:

K_i – an index of scaling an attribute which describes the i^{th} element of the analyzed environment,

$U_i(x_i)$ – utility function of the i^{th} attribute (parameter) of the analyzed environment.

This method has many advantages, such as the introduction of numerical values which describe individual characteristics of the environment. A possible disadvantage is that the outcome may not be easily readable, depending on how detailed the analysis has been. This method is mainly applied to considerations of the variant locations of the building investment.

The MCE (*Multi-Criteria Evaluation*) analysis is applied to support a decision-making process when several or more than criteria are at hand. The aim is to achieve one, shared result [6, 8]. The first step in an MCE analysis is to determine the criteria which will lead to the achievement of the set aim. The criteria appearing in the MCE can be divided into two groups: hard ones, known as *constraints*: barriers, limitations, and soft ones, called *factors*: parameters, factors.

When using constraints, the results are achieved in the form of a juxtaposition of variants which may or may not fulfill the set requirements. In turn, by using soft criteria, one arrives at a degree of the suitability of given variants for attaining a goal which is set during the analysis. The result thus obtained is not as uni-vocal as the one attained through the application of hard criteria [6]. The suitability is calculated from the formula:

$$S = \sum_{i-1}^{n} w_i \cdot x_i \quad i \in \langle 1, n \rangle \tag{2}$$

where:

S – suitability,

w – weight of a criterion,

x – value of a parameter,
i – a criterion,
n – number of criteria.

In an analysis which also contains barrier-type criteria, the formula looks as follows:

$$S = \sum_{i-1}^{n} w_i \cdot x_i \Pi c_j \tag{3}$$

where there is an additional symbol, namely c_j – j^{th} constraint [6].

The criteria taken for an analysis relate to the need of meeting set requirements by the analyzed variant. Using the Boolean overlay method, for example when selecting a site to be developed, criteria are defined as barriers (e.g. at least 200 m away from a water body, an area with the land slope less than 3°). We then achieve a one-zero suitability raster image (where 1 stands for a suitable site and 0 – for an unsuitable site). The final suitability raster is a simple product of unit suitability raster maps (except for the conjunction in formula 2). In some cases, such criteria can be defined with softer ones, e.g. the further away from a water body the better, the less steep the site, the better, etc. However, this precludes any direct comparison of the distance to a water body and the degree of land slope at a given point. This is the reason why certain standardization of thus defined criteria is carried out according to this formula:

$$x_i = \frac{R_i - R_{\min}}{R_{\max} - R_{\min}} \cdot d \tag{4}$$

where:

x_i – a parameter corresponding to a given condition after standardization,
R_i – value of the parameter before standardization,
R_{min}, R_{max} – the minimum and maximum value of the parameter of the criterion,
d – standardization interval [6].

Standardization is run within a set range, e.g. 0–255. Then, the maximum suitability is 255 and the minimum one is 0. Having completed the standardization, each point in the analyzed variant has an assigned value of suitability within the range of 255.

The method is based on the Analytic Hierarchy Process (AHP) which enables consideration of various criteria which ensure the attainability of a given goal. The underlying assumption is that the goal is attainable through the achievement of partial aims leading to the main goal. The analyzed solution variants meet to a greater or lesser extent the achievement of the major goal. The degree to which the major goal is satisfied by each decision variant is determined by the degree to which main criteria and adequately grouped sub-criteria are fulfilled. The decomposition of a problem makes it easier to perform an assessment and is the essence of the AHP [7, 9]. Three steps (stages), connected in an integrated and logical series, are taken to solve a problem:

1. Structuring a hierarchical model (determination of criteria);
2. Evaluation of the criteria on a 9-point evaluation scale;
3. Evaluation and ordering the variants against the established the priorities (main weights), taking into account the analysis of vectors of partial priorities.

The references [7, 9] contain formulas for calculations carried out in three subsequent stages, which lead to the calculation of values of the priority index. These are:

– calculation of the value of a normalized matrix:

$$\overline{w_{ij}} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{5}$$

– determination of the value of the vector of partial priorities

$$\overline{w_j} = \sum_{j=1}^{n} w_j a_{ij} \tag{6}$$

where:

$$w_j = \frac{\sum_{i=1}^{n} w_{ij}}{n} \quad i, j = 1 \ldots n \tag{7}$$

In order to verify whether the procedure was correct,

– we determine the maximum own value of the matrix:

$$\lambda_{\max} = \frac{1}{w_i} \sum_{i=1}^{n} a_{ij} w_j \tag{8}$$

– the value of the consistency index:

$$C.I. = \frac{\lambda_{\max} - n}{n - 1} \tag{9}$$

– – and the value of the consistency ratio:

$$C.R. = \frac{C.I.}{R.I.} \tag{10}$$

where the *C.R.* should reach the value < 10%

The *R.I.* – an index of random consistency depends on the *n* number of compared elements. The consistency index and ratio can serve as verification of the correctness of setting data which represent mutual relations between determined criteria.

Index methods are based on matrices, in which individual criteria are described with the help of indices and weights defining their importance for the execution of the analyzed project. The number in the top left-hand corner of each cell is the index which describes the immediate effect, while the one in the lower right-hand corner stands for the indirect effect on the examined element of the natural environment. In the middle of each cell there is a sum of effects multiplied by the weight. For both the assessment of the effects on the environment and determination of weights it is necessary to secure expert opinions. This method is especially useful when the analysis must take negative effects into consideration, which in the model table above are represented by negative values of the criteria.

Literature presents many other methods of multi-criteria analysis such as: based on artificial neural networks and fuzzy logic.

3. Selection of significant criteria

To a large extent, choosing the best possible variant of construction investment depends on being able to correctly define and estimate the assessment criteria. They may vary in character [2, 3]. Depending on the phenomenon they describe they can be expressed in measurable units (km, tons, items) or in a non-measurable manner (impact on the environment, formal and legal requirements, a social effect, etc.). These may be strict or soft criteria. When strict criteria (constraints) are applied, the feedback tells us whether or not a given variant satisfies the set requirements. The information obtained from an analysis of soft criteria (factors) shows to what degree the goal which was set during the analysis has been fulfilled [7]. The degree of satisfying the expectations pertaining to the analyzed building project is differentiated by assigning weights to the said criteria. Examples of constraints concerning the selection of a building site are flood plan (At risk of being flooded), private land – can it be purchased?, protected lands. Constraints answer the question whether it will be possible to carry out a building investment project on a given piece of land. Other aspects, e.g. construction solutions or the unwanted impact on the environment, can be considered in a similar fashion.

Soft criteria [7] refer to gradable phenomena. They can be presented in a descriptive form or by assigning weight points for fulfilling the requirements to a higher or lesser degree. Examples of soft criteria are: distance to a public road (in km), costs of the investment (in PLN), attractive surroundings, e.g. parks, recreational grounds, entertainment facilities (a descriptive scale), effect on the surrounding environment – different aspects (a descriptive scale), number of trees to fell (in items).

The starting point for a multi-criteria analysis conducted with any of the mentioned methods consists of an estimation of the importance of predefined criteria. This stage must be completed with the contribution of many experts. Their participation and numerous opinions are required due to the different perceptions of the reality and ongoing processes. Expert opinions tend to vary and standpoints are subordinated to different priorities, systems of values, different scopes of knowledge, education and experience. Expert opinions are collected through interviews, which consist of survey forms. Different survey forms should be prepared for different analytical methods and the questions should be formulated in such a way as to allow the analyst to distinguish the basic input data for further procedures. The assessment of criteria in the MUAT and MCE methods is performed with the criteria being divided into constraints and factors. The assessment can be a one- or two-stage procedure. In a one-stage protocol experts are given a survey with a prepared list of criteria and answer questions about their importance, using a scale proposed in the questionnaire for this purpose. Following an analysis of the results, it is possible to verify the proposed list of criteria. In a two-stage procedure, the first step involves asking experts to state what criteria they consider important. Based on the replies given, a list of criteria is structured and submitted to an evaluation in the second stage of the procedure. In the AHP method, a person gives their opinion (using an AHP fundamental scale of comparisons) and responds to two types of questions, regarding the power of the advantage of compared elements versus a given criterion (which is more advantageous?): – which of the two given sub-criteria affects to a greater extent the third element, which is the main criterion? Apart from pairwise comparisons, in a decision support AHP protocol it is also possible to employ real (actual) numerical data or statistical data related to our problem or some of it (e.g. values representing costs, achieved technical parameters of an investment, etc.).

In the indicator method, the survey addressed to experts is different from other questionnaires in that that the analysis will also include evaluations of the negative consequences of the planned investment. The surveys therefore also contain questions about the consequences with a different scale for replies. When analyzing variants of an investment with this method the criteria can be assessed on a scale, for example, from –5 to +5. This approach also enables respondents and analysts to evaluate the adverse effects of a given development project.

4. Basic methods of aggregating opinions and preferences

Experts chosen to provide data for an analysis usually work according to one of the two paradigms. The first one involves cooperation while making an assessment of the criteria within the group examined. By sharing and exchanging opinions, individual experts assign the importance (weights) or evaluate the effect on attaining the goal and the results of their assessment are then averaged. Typically, a geometrical mean of the assessments provided by individual experts is applied to this aim. Divergent opinions can be obtained, hence there is a possibility to discard some information which is too discrepant from the rest of the data. This method needs experts who are familiar with it but it also enables analysts to obtain data ready for analytical processing. The other type of protocol relies on surveys in the form of tables, so that experts work independently and assign points according to the scale imposed by the analyst. The data thus obtained requires further processing and may need to be completed, while the whole survey may have to be repeated several times due to some inconsistency of the results.

If expert opinions are gathered in order to perform an AHP analysis, then all criteria and sub-criteria on the same level are compared pairwise [2, 3]. The assessments refer to a group of n attributes and generate a matrix of assessments, which are composed of assessed elements *aij* (*k*). In other methods, it is necessary to assign weights to individual criteria. Some preliminary analysis is required before information about weights is gathered, or else reasonable intervals must be set for which points or descriptive assessments will be assigned. These intervals should be established so that the status that will decide on the higher or lower value given to each attribute can taken into consideration.

Values of weights expressing preferences relative to subsequent attributes can be determined, for example, by using one of the most highly recommended methods: the logarithmic least squares method (LLSM) [10], better known as the simple geometric mean (SGM) method [2, 3]. Values of weights of attributes are:

$$P_i = \sqrt[n]{\prod_{j=1}^{n} r_{ij}} \tag{11}$$

For practical reasons, associated with the aggregation of hierarchies of sub-criteria, it is generally expected that weights should add up to one. This is why [2, 3] it may be necessary to perform normalization of weights:

$$\overline{p}_i = \frac{p_i}{\sum_{j=1}^{n} p_j} \tag{12}$$

While analyzing results derived from reports worked out by experts one should take various circumstances into account. Due to the degree of complexity of the decision to be taken, it is justifiable to make an attempt to secure diverse opinions. Another justification is that different expert may have gained different knowledge and know-how. Consequently, one may use vectors of preferences, defining hierarchical lists prepared by experts. Such hierarchies can, for instance, include experts' experience or usefulness of their knowledge in each specific case.

5. Conclusions

The nature of investments in the building industry means that while planning a construction project it is obligatory to consider opinions of different groups interested in a given development and to include some information which is difficult to measure. Dynamic changes in the environment and a huge variety of aspects which will eventually affect the shape of building structures make flexible decision-support instruments extremely useful. The great diversity of analyzed aspects translates into an equally great number of criteria, which should be considered by decision-makers. Multi-criteria analytical methods, briefly presented herein, should include many criteria, but before they are applied, some data about a series of conditions which will govern a planned investment should be collected and analyzed. The information discussed in this article proves that there are many approaches which enable us to take advantage of the benefits offered by these methods.

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ELŻBIETA RADZISZEWSKA-ZIELINA, BARTŁOMIEJ SZEWCZYK*

ANALYSIS OF METHODS FOR ASSESSING PARTNER RELATIONSHIPS IN CONSTRUCTION PROJECTS

ANALIZA METOD OCENY RELACJI PARTNERSKICH W PRZEDSIĘWZIĘCIACH BUDOWLANYCH

A b s t r a c t

In the world of literature, only a few methods for assessing partner relationships in construction project have been described. This paper analyses five of them. Methodology is discussed as well as the advantages and disadvantages of each individual method. On this basis, the guidelines for the development of a comprehensive system of assessment and control of partner relationships have been summarised.

Keywords: project partnering, construction industry, assessment methods

S t r e s z c z e n i e

W światowej literaturze przedmiotu opisanych zostało zaledwie kilka metod oceny relacji partnerskich w przedsięwzięciu budowlanym. W artykule dokonano analizy pięciu z nich. Omówiono metodologię oraz wskazano zalety i wady poszczególnych metod. Na tej podstawie zestawiono wytyczne do opracowania kompleksowego systemu oceny i sterowania relacjami partnerskimi w przedsięwzięciu budowlanym.

Słowa kluczowe: partnerstwo w przedsięwzięciu, budownictwo, metody oceny

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1. Introduction

It can be stated in a simplified way, that a partnership, in contrast with competition, is characterized not by struggle but by cooperation. This is a new trend in the approach to the realization of construction projects. Divergent interests are being replaced by the will to share common success in completing construction projects. Companies work together, with the goal of achieving the target result and mutual benefits." [1] Maintaining partner relationships in the implementation of construction projects brings a number of benefits, such as reducing disputes, improving communication, increasing productivity and reducing the time and cost of the project, as indicated by [2, 3]. It was therefore necessary to create a system for the assessment of construction projects partner relationships in construction in order to maintain them at the highest possible level and to control them. In recent years, a series of works on this subject have been published [4–11]. Crane et al. [4] provided guidelines for the selection of measures of partnering in such an assessment system. Lo et al. [5] used a balanced scorecard to determine strategic objectives, which are the measures of the effectiveness of a partnering. However, they do not present actual assessments of partnerships. Some publications, such as [6, 7] show examples of methods for assessing partnerships, however, these are limited to the designation and monitoring of measurements and indicators. On the other hand, [8–11] present complete assessment methods for partner relationships in construction projects, including synthetic indicators connecting all studied measurements. Of these studies, only [10] is a domestic (Polish) study on this subject. The article presents an overview of the various methods and their analysis in terms of advantages and disadvantages, in order to develop a comprehensive method for the evaluation and control of partner relationships in construction projects in the future.

2. Analysis of methods for assessing partner relationships in construction projects

2.1. A questionnaire-based, monthly assessment of partner relationships

A practical way of monitoring partnerships in a project is presented in an article by Bayliss et al. [7]. It shows how problems were dealt with during the execution of a contract for the construction of high-speed rail in Hong Kong. Prior to monthly review meetings, the project participants filled out questionnaires, which assessed thirteen measures of partnering (Table 2) using a five-point scale. Thus the assessments were averaged for individual measures and compared with the previous ones. During the meetings, the assessments of the measures were discussed.

This method requires the organisation of regular meetings of the project participants. Basing the final assessment on the subjective feelings of the participants of the project may cause significant discrepancies in assessment. Also, the method does not allow for designating a synthetic indicator for the overall assessment of the partnership, and only 13 partial assessments without specifying the weight of individual measures. On the plus side, however, it should be noted that the monthly meetings are an opportunity for open communication between the participants of the project, allowing them to develop a better partner relationship.

2.2. Partnering Temperature Index

An automated system for evaluating partnering in construction, utilising a web platform, was created by Cheung et al. [8] For assessing the relationship they used eight measures of partnering recommended by the New South Wales Public Works Department (NSWPWD) of Australia (Table 2). Project participants make a five-point assessment of the achievement of project objectives in view of the individual measures of a partnering; this usually takes place at the end of the month or before each partnering review meeting. Data collected in this way is reported to the project manager, who can review it in the form of aggregated tables and charts. The system provides the ability to track the Partnering Temperature Index for both the specific measures (Measure PTI), calculated as the average rating of individual participants in the project and for the entire project (Project PTI), which is the average of all Measure PTIs. Automatic partnering assessment system PTI enables individual selection of the studied measures by adding new or deleting existing ones, and giving them the desired degree of validity.

An important advantage of the system created its ability to enable project participants to assess partner relationships in their own time and place. In addition, the automated system will calculate both Measure PTIs and Project PTI by itself, which also helps to reduce the time required to process the data collected. The resulting platform is a tool which can help the project manager in assessing and managing relationships in the project. However, he still has to indicate the analysed measures of partnering and the level of their validity, which on one hand allows the assessment method to be easily be adapted to the individual conditions of the project, and on the other hand it requires the manager's knowledge and experience with regard to partnering. Similarly to the method analysed earlier, the assessment using a five-point scale is also intuitive.

2.3. Partnering Performance Index

A computer model for measuring and analysing partnering in construction projects was created by Yeung et al. [9] who formulated a Partnering Performance Index (PPI), which consists of seven Key Performance Indicators (KPIs). These indicators, as well as their validity, were selected during the four Delphi questionnaire survey rounds, carried out among construction experts in Hong Kong which are listed in Table 2. Here the research team conducted five structured face-to-face interviews with field experts and two of Delphi questionnaire survey rounds in order to establish measurable Quantitative Indicators (QIs), which should be taken into account when assessing KPI, and used the theory of fuzzy sets to set Quantitative Requirements (QRs) corresponding to the assessments in a five-point scale. On the basis of the model developed, the PPI computer system was created.

The use of QI and QR allows for solving the problem of the subjective assessment of the project participants. With the use of the Internet, the system provides rapid data collection. This solves the problem of geographical barriers while maintaining low costs. The computer system also reduces the risk of human error, as the data is entered directly by individual participants connected with the project and processed automatically. However due to the diverse characteristics of projects, some restrictions in the system may be apparent. Different values of QR and QI are appropriate for application depending both on the nature of the project and the environment in which it will be implemented. Therefore, it becomes necessary to adjust these values to each particular type of project.

2.4. Project Partnering Volition

The method of assessment is based on the theory of fuzzy sets using AHP analysis, which was presented in work by Chen and Wu [11]. It assumes gathering a team of experts dealing with partnering in the project. Each of them is assigned an influence factor according to their competence, knowledge and experience. The method involves assessment of Project Partnering Volition (PPV) using three parameters: critical factor index (CFI), project management performance (PMP) and participant satisfaction (PS). The team determines the scale of assessments for each value and fuzzy membership function describing the assessment. Then, measures which will be evaluated, are identified. These measures are combined into sections, and thus the CFI takes a hierarchical form. In the example, nineteen measures are proposed, divided into four sections. The exact list of measures is shown in Table 2. The experts then assess the individual measures, indicating: a precise numerical value, a possible range of numerical values, a linguistic term, or a fuzzy number subject. They also define the weighting coefficients for individual measures and sections. Expert assessments are aggregated, and then the fuzzy assessments are determined for the CFI. Assessments for PMP and PS are determined in a similar way. Using parameters determined in this way, the PPV is determined first in fuzzy form, and then as a numerical value.

The advantage of the method presented is the ability of the expert to choose the assessment method of the studied measures. The assessment is based on the knowledge and experience of experts, which reduces the risk of misjudgement. This method, however, is complicated and requires the appointment of a team made up of people with extensive knowledge and experience both on partnering, as well as the theory of fuzzy sets.

2.5. Fuzzy expert system controlling partner relationships (Conrel)

The author developed an expert system for assessing and controlling partner relationships in a construction company, in the context of a strategic partnering. [10] The purpose of this system is to improve the assessment indicators of construction enterprises by raising the level of partner relationships with entities collaborating on the institutional market. The task of the expert system designed is to determine each entity and for each of the 14 measures of the relationships (Table 2) and recommendations for supporting the decision-making system for any construction company, whether the relationships are to be maintained, modified or changed immediately. The next task of the system is to choose the measure of the relationships that should be changed in the first place, because they reduce the efficiency of the company's operations. The decision as to whether the relationship should be maintained, modified or changed immediately, for each of the measures, is made by an expert system on the basis of an analysis of the validity of the measure, and evaluate its impact on company success. In turn, the choice of a particular entity of a measurement to be improved in the first place is made on the basis of the analysis of all input parameters.

The advantage of the method is the control of the improvement of a partner relationship, which is missing in other methods discussed. The system was developed in the context of strategic partnering, so that it would be necessary to adapt the analysed measures for assessment and control of relationships in a construction project.

3. Comparison of the described methods

Chapter 2 presents the methods for assessing partner relationships available in literature. They can be divided into two methods based on statistics, those using the theory of fuzzy sets for assessment. Table 1 summarises the methodology of described techniques and their advantages and disadvantages. Table 2 lists the measures of the partnering in individual methods.

Each of the partnering assessment systems presented involves obtaining information about relationships by filling out questionnaires by the participants of the project. Both in the case of PPI, as well as expert system assessments are set arbitrarily by one person, who reduces the costs associated with it. The PTI and PPI methods use Internet sourced data, which allows for filling out the questionnaires at any time and place. Only the expert system, in addition to the two methods above, has a system that automates the calculations. Fifteen of the tested measures are repeated at least in two of the described methods (Table 2). The PTI method allows for changing both analysed measurements, as well as their validity. In the case of the PPV method, the analysed measurements can also be customised according to the needs. It is similar in the case of the monthly questionnaire-based assessment, but this method does not assume the determination of an aggregate assessment of the partnering, but only a partial assessment of individual measures. With the PTI and PPV methods, the expert system and the monthly questionnaire assessment, a key role is played by the subjective assessment of the participants of the project, which is questionable, since the same status of a given measurement can be evaluated at a different level, by different people. With this in mind, the PPV expert system uses fuzzy logic for the assessment. An attempt to objectify the assessments was used in the PPI method, through the introduction of QIs, which should guide the participant during the assessment. They are also supplemented by QR, in a way creating a grading scale for them. This approach allows for the reduction the subjectivity and differences in the assessments of different projects. Among the described systems, only the expert system allows for the assessment and control of the partner relationship in a construction project.

It is therefore worth considering the development of a comprehensive method based on the following guidelines:

- Selection for assessment of 15 measures present in at least two of the described methods (measures in bold in Table 2),
- Method supplemented by an IT system (as in PTI, PPI, Conrel),
- Assessment made by a single expert (as in PPI and Conrel),
- Method determining the synthetic indicator for all the studied measures (as in PTI, PPI, PPV and Conrel),
- The ability to add and change the studied measures (as in PTI, Conrel),
- Method extended to the control of partner relationships (as in Conrel),
- Control complemented by quantification of the benefits of using the partnering approach used for the cost and duration of the project (not present in current methods).

Table 1

Advantages and disadvantages of methods for assessing partnering source: (own work)

Names of authors	Method name	General characteristics	Advantages	Disadvantages and limitations
Roger Bayliss, Sai-On Cheung, Henry C.H. Suen, Shek-Pui Wong	Questionnaire-based, monthly assessment of partner relationships	Assessment of 13 measures using a five-point scale. Assessment of measures as the arithmetic average of ratings of the project participants	– The opportunity to develop partner relationships on the occasion of monthly meetings – Involving all project participants in a discussion on improving partner relationships – Adaptability	– The need to organise regular meetings – The method is based on subjective assessments by the project participants – Failure to determine the validity of individual measures analysed – No synthetic indicator for all attributes analysed – Involvement of a large number of project participants
Sai On Cheung, Henry C.H. Suen, Kevin K.W. Cheung	Partnering Temperature Index (PTI)	Measures rated using a five-point scale. Measure PTIs as an arithmetic average of project participants' ratings. Project PTI as a weighted average with the Measure PTIs	– The possibility of assessment via the Internet – Automatic calculation of indicators – The ability to adapt the number of measures analysed and their validity to the project	– Selection of measures and their validity requires the manager's knowledge and experience – The method is based on subjective assessments by the project participants – Involvement of a large number of project participants
John F.Y. Yeung, Albert P.C. Chan, Daniel W.M. Chan	Partnering Performance Index (PPI)	7 evaluated KPIs. Each KPI correspond to QI and QR. Project manager gives the value of QIs. Value of QIs are converted to assessment using a five-point scale in accordance with the accepted QRs. PPI is a weighted average of these assessments	– The use of QIs and QRs eliminates the problem of subjective assessments by the project participants – The possibility of assessment via the Internet – Automatic calculation of indicators – No need of involvement of a large number of project participants	– The need to adjust the monitored QIs and QRs to the specifics of the project and the environment in which it will be implemented
Tung-Tsan Chen, Tsung-Chiang Wu	Project Partnering Volition (PPV)	The method uses the theory of fuzzy sets and AHP analysis. Rule database	– The ability to verbally identify the studied factors – Assessment is carried out by competent persons	– Complicated method – Requires the appointment of a team of experts – No IT system
Elżbieta Radziszewska-Zielina	Fuzzy expert system controlling partner relationships	The method uses the theory of fuzzy sets. It provides assessment and control of partner relationship	– In addition to assessment, the system helps control partner relationships – No need of involvement of a large number of project participants	– Need for training in the use of the specially developed Conrel IT system – Used for strategic partnership

Table 2

Measures of a partnering in various methods (own work)

	A questionnaire-based, monthly assessment of partner relationships	Partnering Temperature Index	Partnering Performance Index	Project Partnering Volition	Fuzzy expert system controlling partner relationships
Trust	X		X	X	X
Information sharing	X				X
Communication	X	X	X	X	X
Cooperation and mutual relations	X				X
Standards and rules of behaviour	X				X
Quality	X	X	X	X	X
Safety	X	X			
Financial security	X			X	
Job satisfaction	X				
Resources	X			X	
Waste minimization	X				
Third parties' needs	X				
Dispute resolution	X	X			X
Time		X	X		
Cost		X	X	X	
Environment		X			
Contract relations		X			
Top management commitment			X	X	
Innovation and improvement			X	X	
Dedicated team				X	
Flexibility to change				X	X
Long-term perspective				X	
Partnership formation at design stage				X	
Good cultural fit				X	
Company wide acceptance				X	
Questioning attitudes				X	
Clear understanding				X	
Consistent with objectives				X	
Technical expertise				X	
Equal power/empowerment				X	
Basis of order placement					X
Number of suppliers					X
Approach to service quality control					X
Cost division					X
Participation in the enterprise's new offer					X
Contact frequency					X

4. Conclusions

In the world of literature, only a few methods for assessing partner relationships in construction project have been described. This article analyses five of them. Methodology has been discussed as well as the advantages and disadvantages of individual methods. Because there is no comprehensive method for assessing and controlling partner relationships in construction projects, guidelines for its creation have been developed. The development of this system is in progress and will therefore be the subject of subsequent articles.

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TECHNICAL TRANSACTIONS | **CZASOPISMO TECHNICZNE**
CIVIL ENGINEERING | BUDOWNICTWO

2-B/2014

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FLEXIBLE DESIGNING OF A ROAD INFRASTRUCTURE EXAMPLE

ELASTYCZNE PROJEKTOWANIE NA PRZYKŁADZIE INFRASTRUKTURY DROGOWEJ

A b s t r a c t

The paper presents the idea of flexible design in the construction sector. Guidelines of the evaluation of a road infrastructure were discussed based on JASPERS Blue Book. An idea of how to proceed is presented through infrastructure projects concerned with economic efficiency analysis using a flexible approach. Moreover, the issue of flexibility is presented using the POZNAN BY-PASS A2 as the example of infrastructure, to which efficiency analysis was applied to variant solutions.

Keywords: flexibility, infrastructure, design, net present value

S t r e s z c z e n i e

W artykule przedstawiono idee elastycznego projektowania w budownictwie. Omówiono wytyczne oceny infrastruktury drogowej na podstawie Niebieskiej Księgi JASPERS. Pokazano ideę postępowania podczas analizy efektywności ekonomicznej przedsięwzięć infrastrukturalnych z uwzględnieniem podejścia elastycznego. Zagadnienie elastyczności zostało omówione na przykładzie budowy obwodnicy miasta Poznania POZNAN BY-PASS A2, w którym zastosowano analizę efektywności dla rozwiązań wariantowych.

Słowa kluczowe: elastyczność, infrastruktura, projektowanie, wartość bieżąca netto

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1. Introduction

Rapid technological growth and turbulence in the environment are factors that generate significant difficulties in construction project design, particularly infrastructure systems. The rapid growth of road infrastructure has been closely related to economic growth. Preparing a project design involving readiness for change during its life cycle means designing in a flexibility factor which provides the opportunity for adapting to possible change [1]. Considering the long life cycle of road infrastructure, changes in operating conditions (e.g. traffic load) and applicable requirements (such as increasing the acceptable ratings – traffic load categories), modernization and conversion of establishments is also given. Nevertheless, it is difficult to determine the exact point of time of their occurrence, or their actual values of the parameters. This supports the introduction of a new approach, based on flexibility, which can be interpreted as a possibility (however not a requirement) to introduce certain options with the assumption of changing the configuration of a system parameters or system components in time [11].

The purpose of this article is to present a flexible approach to designing in the construction sector. In terms of the scale of operations, the case under consideration refers to the construction of a part of the Poznań by-pass (POZNAŃ BY-PASS A2) as an example of infrastructure. In the life cycle of such a construction (which are often system components, such as a system of motorways, airports, etc.), one should consider changes in the requirements and parameters of supported processes in time [17]. Typically, a growing tendency is the assumption for this type of argument (e.g. gradually increasing number of buffer parking lot users, number of airport passengers, increase of number of motorway users, etc.).

2. Typical infrastructure design vs. flexible approach

Commonly encountered problems in managing construction processes have encouraged numerous researchers to attempt to resolve them. Sources of the approaches discussed can be specified chronologically, constituting development milestones over a perspective of several dozen years:

- The idea of flexibility in production management was described by Schumpeter in 1934 [12]; he saw the reasons for introducing flexibility in the necessity to build an efficient response to changes in the environment,
- The concept of buffering was presented by Kaplinski (1978) in a discussion regarding the issue of construction process harmonization [7],
- The key role of flexibility in planning and designing regarding the ability to adapt the response to changing operating conditions, in contrast to the traditional approach in engineering design, consisting of searching for a single best solution (De Neufville 2000, 2004) [2, 3],
- Analyses of construction processes with the use of flexibility, conducted by Thomas'Team (Horman, Thomas 2005; Thomas, Horman 2006; Thomas and Ridley and Sanvido in. 1999) [4, 15, 14],
- Application of flexibility in managing construction projects focused on operations on a tactical level (Olsson 2006) [9],

- Identification of both internal and external uncertainty factors supporting the need to apply flexibility (Mayer, Kazakidis 2007) [8],
- The concept of FLEMANCO, a flexible construction process execution management method, was proposed by Paslawski in 2009 [10],
- Application of multi-criteria choice in designing infrastructure was developed by Zavadskas and Vaidogas (2009) [16],
- Jaskowski and Sobotka (2012) pointed to the options of applying a flexible approach through alternative changes of process execution sequence in a network model [5],
- Shahu *et al*. (2012) indicated the need to consider flexibility in planning construction processes, beside typical criteria (cost, deadline, quality) [13].

In the traditional approach, the number of design and implementation variants is gradually reduced during planning. Engineering is usually based on a single key value (such as traffic load), without considering any possible changes of this value in time, thus producing very limited information about the actual values (it would be much more advantageous to define, for example, a range of values which might occur). Consequently, a designer acting in accordance with applicable specifications, codes and standards, as well as frequent financial restraints imposed by the investor, would usually produce a design with minimal options for further variants. However, the further we are from the point of taking decisions about the adopted design parameters, the harder it becomes to anticipate the actual requirements of the system. This is presented in ideographic form on Fig. 1. The introduction of flexibility serves the purpose of avoiding a situation when the construction ceases to meet the applicable requirements after a relatively short time, or does not match current requirements (and therefore generates losses) as a result of overly optimistic assumptions. In the approach presented, flexibility means assuming the option of changes in the construction (or system) during its life cycle to enable its adaptation to varying environmental conditions.

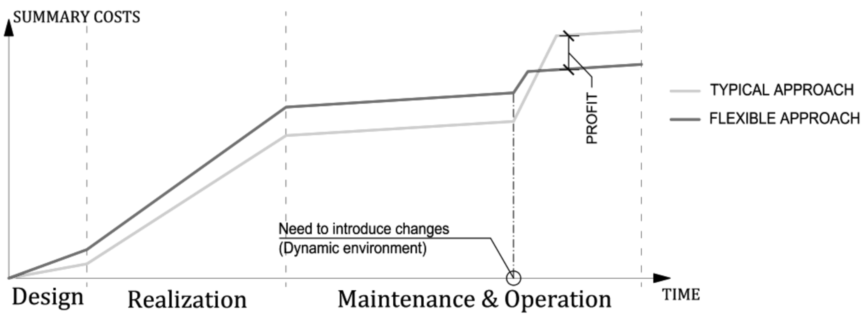

Fig. 1. Cost account in the investment process

3. Blue Book – guidelines for assessment of road infrastructure

At the end of 2008, an instruction book was written, presenting cost-benefit analysis (CBA) methods, referred to as the Blue Book [6].Complying with its main guidelines in all projects financed with public funds is highly recommended. The purpose of the techniques presented in the Blue Book is to provide assistance in choosing the optimum solution which will provide both economic and social advantages while guaranteeing the most efficient manner of utilising public funds.

According to the CBA, the first phase of project assessment is the identification of alternative variants in terms of the project goal, execution possibilities, and feasibility studies. This article disregards that chapter because the analysis relates to construction of the POZNAŃ BY-PASS A2, which is part of the motorway ring around the city of Poznań at the Poznań Komorniki – Poznań Krzesiny section of A2 motorway (ca. 13 kilometres). The research pertains to the following three variants for executing this project:

– initially building three lanes in one direction;
– building two lanes in one direction, with the option of adding another lane later, with prior adaptation of the infrastructure (bridges and viaducts) to extension;
– building two lanes in one direction, with the option of adding another lane afterward s, without prior adaptation of infrastructure.

3.1. Phase II – Socio-economic analysis

The purpose of this analysis is to demonstrate that the proposed investment variant is beneficial from a social perspective. Economic analysis was carried out on the basis of the so-called accruals method and economic profits are determined on the basis of the difference between total economic costs in non-investment variant (NV) and equivalent costs in one of the investment variants (IV).

3.1.1. Economic Net Present Value *ENPV*

The main formula defining the economic efficiency calculation is as follows:

$$ENPV = \sum_{t=1}^{n} \frac{NB_t + NC_t}{\left(1 + \frac{r}{100}\right)^t} \tag{1}$$

where:

- $ENPV$ – Economic Net Present Value,
- NB_t – efficiencies for users and the environment in the consecutive year t,
- NC_t – net road costs in the consecutive year t,
- n – years over the period of analysis,
- r – discount rate (%).

Net road costs are calculated as the difference between road costs in no-investment and investment variant $\left(\boldsymbol{C}_t^{[WO]} - \boldsymbol{C}_t^{[WI]}\right)$ the same procedure should be followed when calculating efficiencies for road users and the environment. In order to determine the economic net present value, you should sum up discounted net benefits for each year, being the sum calculated on the basis of the following formula:

$$NV_t = NB_t + NC_t \tag{2}$$

and

$$C_t = c_b + (c_m) + c_o + c_r + c_u \tag{3}$$

where:

$c_b(c_m)$ – construction (reconstruction) costs,
c_o – periodical overhaul costs,
c_r – partial overhaul costs,
c_u – daily maintenance costs.

$$B_t = b_e + b_c + b_z + b_w + b_s \tag{4}$$

where:

b_e – vehicle service costs,
b_c – time costs in passenger transport,
b_z – time costs in cargo transport,
b_w – costs of traffic accidents,
b_s – costs of emissions of toxic exhaust gas components.

3.1.2. Benefit-Cost Ratio *BCR*

Efficiency evaluation is expressed through the *BCR* calculation ratio, describing the proportion of benefits to costs. It is calculated as the sum of discounted annual benefits to the sum of discounted annual net road costs for the audited period, according to the following formula:

$$BCR = e = \left| \frac{\sum_{t=1}^{n} v_{rt} \cdot NB_t}{\sum_{t=1}^{n} v_{rt} \cdot NC_t} \right| \tag{5}$$

where:

$BCR = e$ – economic efficiency ratio,
v_{rt} – discounting factor in the consecutive year *t* of the period under review,
NB_t – efficiency for users in the consecutive year *t* of the period under review,
NC_t – road costs in the consecutive year t of the period under review,
n – period of analysis.

We conclude that an investment is efficient when $BCR \geq 1$

3.1.3. Economic Internal Rate of Return *EIRR*

An investment project can be accepted when: $EIRR > RRR$ meaning that the minimum threshold return rate is less than the discount rate [6], at which *ENPV* is nil. Namely:

$$ENPV_r = \sum_{t=1}^{n} \frac{NB_t + NC_t}{\left(1 + \frac{r}{100}\right)^t} = 0 \tag{6}$$

4. Case study

The presented infrastructure design case is a 13-kilometre section of the southern ring of Poznań, section of the A2 motorway. Due to its function and connection of two critical locations in Poznań, increasing volume of users should be considered for this road section. To illustrate the benefits of applying flexibility, two variants of the project have been prepared:

W1 – Building the road with three lanes at once, irrespective of demand fluctuations (Big One option).

W2 – Building the road with two lanes in the first stage and optional extension during the following years with another lane, according to traffic intensity (Step By Step option).

The principal assumptions of both options are as follows:

- both variants are compared to the so-called non-investment variant (W0), i.e. existing city road connecting the same critical points of Poznań as the designed variants;
- road service and maintenance costs have been calculated on the basis of cost indicators specified in the Blue Book issued by Joint Assistance to Support Projects in European Regions (Jaspers);
- the indicators were read on the basis of calculated rates of travel for each of the variants separately. They depend on the average daily intensity of passenger cars, vans, trucks and buses;
- all cost indicators were determined for specific years of forecast separately, applying relevant growth rates.

Initially, computations were carried out for a 25-year term NPV analysis as a universally used method. They also carried out an analysis for the period of c 60 years.

NPV outputs for both options: Big One (no flexibility) i Step By Step (with flexibility options) The results obtained are presented on Fig. 2. Comparison of NPV changes for both options indicates a clear advantage of the flexibility option.

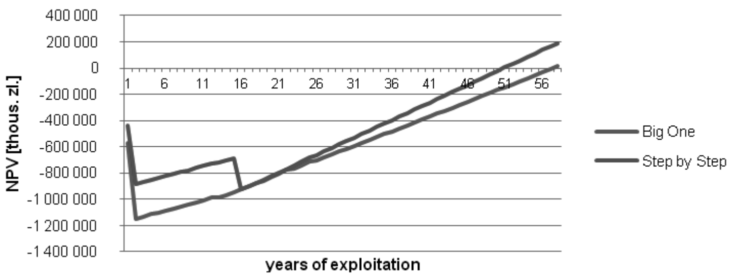

Fig. 2. NPV analysis for POZNAN BY-PASS A2

NPV for the Big One option initially covers a range of high negative values and would only reach positive levels after 57 years. The level of measures invested in the first year amounts to a value 35% higher for the variant Big One. The payback period (NPV = 0) for the Step By Step variant is about the 14% less than in the case of the Big One.

These calculations do not take certain technical and environmental factors, cooperation with UE and regional development factors which are very important for designing a traffic system, arising from city ring construction, e.g. movement of heavy vehicle transport outside the city, obtaining an EU grant, extension of the shipping network within the motorway area into account

The results obtained corroborate the idea of introducing flexibility, consisting of the mitigation of possible losses and enhancing the options for taking the opportunities. In the case under consideration, this option involved a limitation of the number of road lanes at the outset of the project and making the addition of another lane a contingent upon increasing volume of road users.

5. Conclusions

With the fundamentals of flexible approach in infrastructure design presented above, and with an example implementation, the following conclusions can be drawn:

1. 1Proactive attitude is of crucial importance for introducing flexibility in design, as opposed to the reactive attitude prevailing in the traditional approach;
2. Based on the average value calculated through determination, is a disadvantage of traditional design engineering which, considering the long life cycle of the facility, may lead to the inferior adaptability to the variable environment (higher costs, compared to proceeding in accordance with the flexible approach);
3. The presented NPV change analysis for the different options turned out to be an effective method of estimating the results of applying flexibility in the case under consideration;
4. The value of flexibility is given by uncertainty – one can add a new line on request (watching traffic problems vis a vis maintenance cost);
5. In terms of the flexibility application, the following are the main important elements:
   - scale of uncertainty impact (number of factors and range of possible changes),
   - life cycle phase considered (generally, introduction of flexibility in design engineering seems to be particularly beneficial considering the high potential for uncertainty).

The results presented prove the relevance of the applied method. In the case study under consideration, the costs of restarting the construction procedure with the next stage must be taken into account (they seem to be extremely low, as compared to the costs considered in the presented model). A hybrid approach, involving other methods was also considered for implementation in future research.

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TECHNICAL TRANSACTIONS | **CZASOPISMO TECHNICZNE**
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MARIUSZ REJMENT**

RANGE OF APLICATION AND LIMITATIONS OF THE EARNED VALUE METHOD IN CONSTRUCTION PROJECT ESTIMATION

ZAKRES STOSOWANIA I OGRANICZENIA METODY EARNED VALUE DO OCENY PRZEDSIĘWZIĘCIA BUDOWLANEGO

A b s t r a c t

The considerable degree of complexity found in construction work, as well as project susceptibility to unpredictable conditions determines the need of ongoing progress monitoring and continuous time-cost analysis during the execution of work. Financial and material analysis, using the Earned Value method applied to the construction of an Underground Gas Storage Facility, including project risks which occurred during the project, helped to identify the advantages and limitations in application of this method of monitoring work progress.

Keywords: time-cost analysis, risk assessment, Earned Value Method

S t r e s z c z e n i e

Znaczny stopień skomplikowania robót budowlanych oraz wrażliwość przedsięwzięć na warunki losowe warunkuje konieczność bieżącej kontroli postępu i permanentnej analizy czasowo-kosztowej w trakcie realizacji. Przeprowadzona w artykule analiza rzeczowo-finansowa, przy wykorzystaniu metody Earned Value budowy Podziemnego Magazynu Gazu, z uwzględnieniem występujących w ramach przedsięwzięcia ryzyk, pozwoliła na wskazanie zalet oraz ograniczeń w stosowaniu wspomnianego sposobu kontroli postępu robót.

Słowa kluczowe: analiza czasowo-kosztowa, ocena ryzyka, metoda Earned Value

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1. Introduction

Construction projects are a subject to a number of factors which interfere with their smooth completion. It is, therefore, important to monitor the progress of work in real time, and systematically analyse any variation in work schedules and project costs compared to the value previously planned, in order to take preventive measures and thus minimize the negative impact of confounding factors. The literature [1–16] quotes the different methods and techniques facilitating the analysis of projects, enabling a comprehensive risk assessment while supporting the decision making process in construction industry. Great attention is drawn to methods which ensure control over projects using a relatively un-sophisticated mathematical methodology, with the simultaneous determination of the likelihood of completing investments on time and within a budget. The Earned Value Method, discussed and exemplified in the example presented in the paper, is one of the most popular methods enabling such monitoring.

2. Methodology of Earned Value Management

The Earned Value method is one of the most popular methods used to monitor and control the progress of work. It was initially used for US Government financial analysis. Currently, it is an essential tool used for Project Management and Cost Engineering. It is also popular in the U.S. Department of Defense, NASA and also in the construction industry. Official normalization of the EV method took place in 1967, when the U.S. Department of Defense introduced the C/SCSC standard (Cost/Scheduling Control System Criteria) describing the 35 criteria which should be applied to control cost and work schedules. Between 1995 and 1998, the EVM was adapted in the industry under the heading of ANSI EIA 748-98 standard. Here, in contrast to the traditional approach of cost comparison, the scope of the work actually carried out on site is taken into account. The analysis is based on several measurements utilizing appropriate indicators. Measurements are taken at regular intervals, e.g. at the end of the month, tracking the trends and variations of those indicators. Indirectly, we can use EVM to control risk in the context of exceeding project costs and failure to meet the deadline of completion of the investment. As the authors of the publication [2–5, 11, 12, 15, 16] stress, the primary purpose o EVM is to measure the progress of the project, predict its total cost and completion date, as well as analyze any inconsistencies between the schedule and the budget.

3. Analysis of construction of the Underground Gas Storage Facility

Implementation of the analysed contract was planed in “the DESIGN and BUILD system”. The system assumes that the Contractor is expected to develop detailed technical documentation of structures to be built and select technologies and technical equipment. In theory, it allows the Client to reduce the number of highly specialized staff and the total cost of the task, and allows the Contractor to retain greater flexibility and select both technically and economically optimal solutions. In reality, it is a way of transferring the risks associated with the elaboration of the design documentation, into the Contractor, while the Client is hardly accountable for delays and additional costs associated with this part of the task.

3.1. Hazards and risks

Due to the nature and complexity of construction work carried out during the realization of the Underground Gas Storage Facility (USF), many factors came up, affecting both the timeliness and finances linked to the project. A list of examples of the hazards and risks sources is presented below:

- Limited time spent by the Client on final execution of construction work which caused delays at the design phase and followed through into the implementation period. Delays in the design work which directly translated into delays in the commencement of construction work, and not only regarding the structure under construction but also related construction works. The need to break up the design work and delegate it to a number of design offices caused numerous coordination problems;
- High level of expertise expected from companies involved in the construction made it necessary to set up a consortium. The division of work, necessary to determine the scope of responsibility of each member of the consortium, has caused a tendency to restrict planning to individual portions of the task, not taking the needs and potential of other parties into account;
- Limited space on the building site, in connection with the number of companies and individuals involved, limit the possibility of the simultaneous storage of materials (forcing the need for careful scheduling of deliveries). This generated inconveniences associated with, for example, organization of the site facilities or availability of parking spaces;
- The entire design and construction process was subordinated to the technological process. Technological equipment delivery and installation delays had a disproportionately large impact on the contract, in comparison to the time required for the installation, and became (in addition to delays in designing work) the most serious reason for delays in relation to the schedule;
- Considerable scope of construction work covered by the contract meant the need to involve enormous human resources. In reality, it meant several companies organized in a structure with several levels of subcontracting relationships. Apart from the coordination problems, delays on the work front caused by one of the companies very often made it difficult, or even impossible for the others to work.

3.2. Construction work and financial analysis of the project

The starting point for the analysis, using the EVM, was the construction work and financial schedules or their parts (tasks organized over time with assigned financial resources). On this basis, with respect to the assumed duration, the base BCWS and cost curve of planned costs (Budgeted Cost of Works Scheduled) was defined, showing increasing costs of tasks, while additional parameters were defined (including SV and SPI indicators for each accounting period). The analysis was performed for both the entire project and for each of the built structures separately, taking into account various random factors.

3.2.1. Modifications in BCWS curve for the construction of the USF

The first factor threatening the smooth realization of the USF construction project appeared as early as in the first months of construction. Despite making the technical designs of buildings available (including the administrative building, the sources building) for execution, the design work on the main technological sequence had not started. The developed concept required such extensive changes in relation to that which had been previously presented by the Client that it became necessary to work out an alternative technical design and apply for a replacement building permit. The situation was made more serious by delays in the reporting data regarding machinery and equipment by the members of the consortium. Subsequent updates of material and financial schedule, issued in the form of revisions, were produced during the course of construction work (Fig. 1).

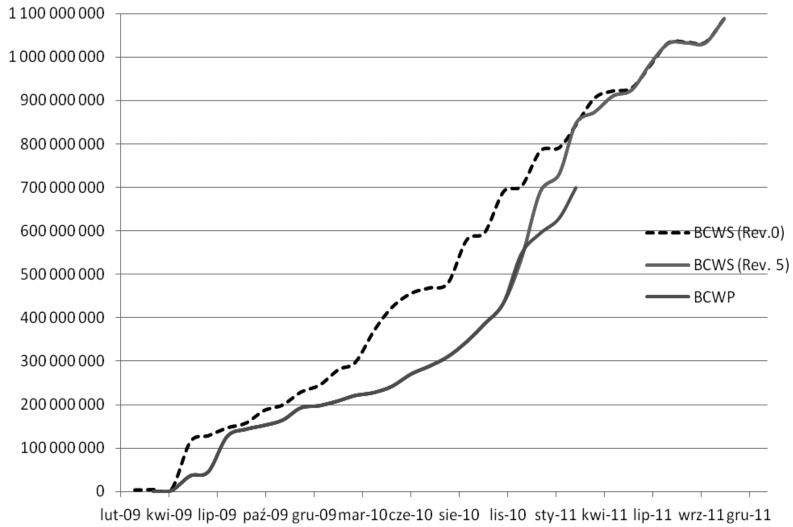


Fig. 1. The impact of subsequent revisions of material and financial schedule on the shape of the BCWS curve. The progress of construction work in the end of March 2010

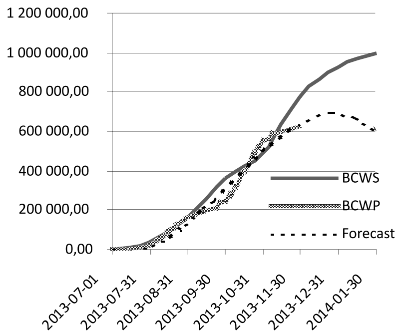
By mid contract, SV reached almost 10% of the contract value, and SPI decreased (PV = 429 372 353,93 PLN, EV = 306 898 504,63 PLN SV = –122 473 849,30 PLN, SPI = 0.71). The surge in progress at the end of 2009 is a good example of the sensitivity of EV method to unreliable data, as the described increase resulted primarily from the financial settlement of work at the end of the year which, in fact, would actually be completed at a later date. Almost zero revenue in January and February 2010 is proof of such a source of the surge. In the second half of 2010, as a result of the involvement of an additional design office, most of the technical drawings were completed and submitted for execution, resulting in an accelerated the pace of work. Better indicator values seen in the middle of that year could be noted (PV = 676 361 628,13 PLN SV = 643 542 647,78 PLN SV = –32 818 980,35 PLN, SPI = 0.95), which confirms the increase of the curve BCWP in Figure 1. Despite the implementation of the recovery plan (another revision of the schedule) and the delivery of the majority of equipment, progress was far from what was expected. The situation was further complicated by cold and snowy winter weather, followed by a thaw, which paralyzed the construction site for two weeks and substantially damaged the temporary access roads. At the end of March 2010, the indicator values were as follows: PV = 848 081 324,58 PLN, EV = 699 161 945,27 PLN SV = –148 919 379,31 PLN, SPI = 0.83 (6 months before the scheduled deadline of work).

3.2.2. The impact of bankruptcy risk of a company on the construction of the warehouse-service building

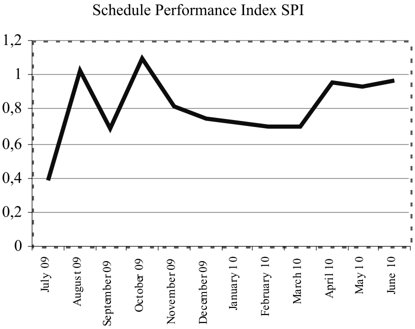
The warehouse-service building was selected for detailed analysis in order to present risks resulting from disruptions and discontinuations of construction work as a result of a subcontractor's declaration of bankruptcy. Procedures related to the choice of a replacement subcontractor, and new pricing for the remaining scope of construction work resulted in a two month discontinuation of construction work and an the increase of the final cost.

Although the construction work started with a slight delay in relation to the schedule, all the foundations and 50% of backfills were completed in August. All steel structure elements were delivered to site, a large part of which (mainly columns) were pre-assembled. This resulted in the liquidation of the initial delay, work was now just ahead of schedule, as indicated by SPI at 1.03 (PV = 154 637,17 PLN, EV = 158 711,65 PLN SV = 4 074,48 PLN, SPI = 1, 03). This indicator is not, however, completely reliable, and again demonstrates the sensitivity of the EV method to the manner of entering data. A 100% delivery of steel structure elements was considered to be a part of the completed work, in spite of the fact that, actually, only about 60% of the steel structure had been installed. This significant value of structural elements resulted in an overestimate of the achievements. In such cases, in the EVM analysis only values supplied materials in proportion to the amount actually installed, so only this should be take into account. With such an approach, the SPI value decreased to 0.95. The projected work completion date was the end of October 2009 (which meant two months ahead of schedule). After a very successful August and September 2009 a significant slow-down in progress, primarily due to a delay in laying the flooring and the building of brick partition walls (PV = 359 118,03 PLN, EV = 246 258,47 PLN SV = –112 859, 56 PLN, SPI = 0.69). The projected completion date, consistent with that assumed – EACT = 3.46 months. In November, the progress of construction work was so slow, that it seriously threatened the completion date, which raised management concern. The subcontractor was requested to submit and implement a recovery plan. Then, the indicators were as follows: PV = 776 626,42 PLN, EV = 627 364,76 PLN SV = –149 261,66 PLN, SPI = 0.81. January 2010 marked an actual interruption of work by the subcontractor. The only work carried out during this month (completion of wall panels installation, and the roof) was done by a previously hired specialized company. At the end of the month, the subcontractor informed the main contractor that they would be declaring bankruptcy and left the construction site (PV = BAC = 1 000 000,00 PLN, EV = 716 370,21 PLN SV = –283 629,79 PLN, SPI = 0.72). The procedures relating to the selection of a new subcontractor, as well as the winter period resulted in the resumption of work as late as in April 2010.

The example discussed above shows the way the EV method can be used to recognize danger signals threatening the continuity of construction work. Steadily decreasing SPI values at the end of the year, in conjunction with the flattening of the BCWP curve, clearly indicated a significant decrease in the pace of work, jeopardizing the timeliness of construction – c.f. (Fig. 2).



Progress in November 2009.
Forecast line (trend) drawn using a second degree polynomial



Changes in SPI in periods.

Fig. 2. Progress in subsequent accounting periods

4. Strengths and limitations of the Earned Value Method – the example of USF construction

The Earned Value Method, used in this article to perform a construction work scope and financial analysis of a construction project, is relatively widespread abroad. It had been developed to American and Australian standards [15, 16]. Despite many advantages and the enormous potential, more and more attention is paid to its certain limitations and inaccuracies:

- Referencing deviations from schedule to cost units, and un timed units (a modified method – Earned Schedule);
- Difficulty in analyzing EVM indicators due to change of the so called baseline in view of events in the course of construction work. In view of this, a certain discipline in the construction and maintenance of the schedule is required. This is the case in implementation of innovative projects, where there might be changes and unforeseen events. Then the scope of the budget and the schedule is changed and this, in turn, affects the project completion estimates;
- Subjective way of assessing work progress which, in extreme cases, may lead to deliberate falsification of data in order to present the desired image (for example, desirable from the viewpoint of the board);
- Regarding contracts exceeding completion time limit, there is no clear accountability for contractual penalties which may be charged by the Client;
- Limited applicability of the EVM may result in choosing the flat rate method for contract accounting, widespread in the construction industry. With this approach, it is impossible to define the majority of method indicators, and its usefulness is limited mainly to the fact that it analyzes progress and timeliness of work. Then, this method is only a secondary source of information, indicating some trends rather than accurately forecasting future revenues;

- In the event of changes in the work order, in particular, high percentage ranges of contract value, the schedule and BCWS curve needs to be modified respectively, and only on that basis the actual progress of works should be evaluated;
- According to the theory, this method should take only the tasks already performed (e.g. using milestones) into account. This means that a lot of tasks close to completion can not be taken into account, which will decrease estimates of progress. Therefore, it is advisable to divide the project into smaller parts, and determine a percentage of task progress.

6. Conclusions

It seems that, apart from showing errors in the organization and management of the project related to construction of the Underground Gas Storage Facility, minor inaccuracies should be highlighted when using the Earned Value Method to supervise construction contracts based on flat rate pricing (BCWP curve overlaps with ACWP), however, due to the relatively high sensitivity of the method, it is highly susceptible to entered data. In the situation described, the EV Method should be regarded rather as complementary and supportive to other methods, as well as a convenient way of synthetic presentation of data, for example, to the board. Nevertheless, all these inconsistencies do not diminish its merits and potential.

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TECHNICAL TRANSACTIONS | **CZASOPISMO TECHNICZNE**
CIVIL ENGINEERING | BUDOWNICTWO

2-B/2014

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GREEN PUBLIC PROCUREMENT CRITERIA FOR CONSTRUCTION CONTRACTS

KRYTERIA ŚRODOWISKOWE W ZAMÓWIENIACH PUBLICZNYCH NA ROBOTY BUDOWLANE

A b s t r a c t

This paper describes the legal conditions for the award of Green Public Procurement for construction works. Environmental criteria that can be used in contracts for construction works are also presented. The author presents current practice in green procurement organized by Polish authorities.

Keywords: Green Public Procurement, environmental criteria, works

S t r e s z c z e n i e

W artykule przedstawione zostaną uwarunkowania prawne udzielania zielonych zamówień publicznych na roboty budowlane. Zaprezentowane zostaną kryteria środowiskowe, które mogą być stosowane w zamówieniach na roboty budowlane. Autorka przedstawi również dotychczasową praktykę w udzielaniu zamówień zielonych przez polskich zamawiających.

Słowa kluczowe: kryteria środowiskowe, zielone zamówienia, roboty budowlane

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1. Introduction

Green Public Procurement is "a process whereby public authorities seek to procure goods, services and works with a reduced environmental impact throughout their life cycle when compared to goods, services and works with the same primary function that would otherwise be procured" [8].

Through the use of ecological criteria, contracting authorities may significantly affect the development and dissemination of environmental technologies. Green Public Procurement can therefore be an important factor in stimulating market innovation and encouraging the creation of eco-friendly products. Green Public Procurement can also provide financial savings throughout the life cycle of product.

European Union legislation imposes mandatory requirements for the procurement of certain goods and services, for example by setting minimum efficiency standards. Mandatory requirements also apply to the construction sector. Since 2013, all new construction projects and major renovations projects (e.g. renovation of more than 25% of the external walls or if the cost of the renovation exceeds 25% of the building value) excluding the value of the land, will have to use the minimum energy performance requirements.

From 1 January 2019 all new buildings used and owned by public authorities must be buildings of nearly zero energy (Directive 2010/31/EU on the energy performance of buildings).

In addition, some Member States have specific provisions under which mandatory standards for Green Public Procurement in relation for specific sectors or types of contracts are created [7].

1.1. Legal provisions

Polish regulations on Public Procurement is tailored to the requirements of European Union legislation, including Green Public Procurement.

1.1.1. European Union legislation

The basic legal acts adopted at EU level policies regulating Public Procurement are: Directive 2004/18 [4, 7] of the European Parliament and of the Council of 31 March 2004 on the coordination of procedures for the award of public works contracts, public supply contracts and public service contracts and Directive 2004/17/EC [5, 7] which covers the procurement procedures of entities operating in the water, energy, transport and postal services sectors. Directives clarify how the authorities may contribute towards environmental protection via Public Procurement. According to recital 5 of the Directive 2004/18, the Directive itself "clarifies how the contracting authorities may contribute to the protection of the environment and towards the promotion of sustainable development, whilst ensuring the possibility of obtaining the best value for money for their contracts". Similar conditions for eco-labels are set in Directive 2004/1717. The last part of the said Directives that might be useful for the promotion of GPP is article 53 of Directive 2004/18. It states that: the criteria on which the contracting authorities shall base the award of public contracts shall be either:

a) when the award is made to the most economically advantageous tender, from the point of view of the contracting authority, various criteria linked to the subject-matter of the public contract in question, for example, quality, price, technical merit, aesthetic and functional characteristics, environmental characteristics, running costs, cost-effectiveness, after-sales service and technical assistance, delivery date and delivery period or period of completion, or
b) the lowest price only.

Therefore, Contracting authorities may choose to award the contract with the lowest price, or to the most economically advantageous one.

The Directive focuses on procedure rather than on the subject matter – it regulates how public authorities should proceed with Public Procurement rather than what they should buy. Directives emphasize a desire to obtain contracts with best value for money, providing the opportunity to take account of environmental issues in subsequent stages of the procurement procedures:
– at the stage of the subject-matter description (art. 23 Directive 2004/18/WE),
– at the stage of contractors qualification (art. 45, 48 i 50 Directive 2004/18/WE),
– at the stage of selecting the best bid using environmental evaluation criteria (art. 53 Directive. 2004/18/WE),
– at the stage of determining the conditions of the agreement (art. 26 Directive 2004/18/WE)[4, 6].

The EU has created a number of acts that are indirectly related to green procurement, such as the Directive of the European Parliament on The energy performance of buildings, energy efficiency, promote the use of energy from renewable sources and a number of other.

1.1.2. Polish legal regulations

The basic act regulating issues relating to Public Procurement in Poland is the Act of 29 January 2004 – Public Procurement Law (Journal of Laws of 2013, No. 907, 984, 1047, 1473) [2], hereinafter referred to as PPL. In the Act PPL environmental issues are indicated in three articles.

In art. 30 paragraph. 6 it is said that the contracting authority may not describe the subject-matter of the contract on the basis of the terms of reference through Polish, European or international standards, where it will provide a precise description of the subject-matter of the contract by indicating functional requirements, which may include a description of impact on the environment.

Article 91 paragraph. 2 states that tender evaluation criteria shall be price or price and other criteria linked to the subject-matter of the contract, in particular quality, functionality, technical parameters, use of best available technologies with regard to the impact on the environment, exploitation costs, after-sales service and a period of contract performance.

In Article 24 paragraph. 1 point 4–8 on the list of crimes for exclusion from Public Procurement procedure an offense against the environment can be found. In accordance with provisions of the award of a public contracts, which excludes persons or partnerships, commercial law and legal entities who are connected to officers, general partners or members of the Office of the management body who have been validly sentenced for an offense against the environment.

In order to confirm that offered works comply with requirements laid down by the contracting authority, the contracting authority may request a certificate of an independent entity responsible for compliance with the economic operator's activities with European environment management standards, if contracting authorities indicate environmental management measures to be used by the economic operator when performing a contract for works or services, referring to the Eco-Management and Audit Scheme (EMAS) or environment management standards based on European or international standards certified by entities operating in accordance with the EU law, European or international certification standards.

The Contractor may also submit equivalent certificates issued by entities domiciled in another Member State of the European Economic Area or other documents confirming the use by the contractor equivalent quality assurance measures and the use of equivalent environmental management measures.

Another legal act which indirectly relates to environmental protection in construction works is the Act of 7 July 1994 Building Law (Consolidated text: Journal of Laws of 2010, No. 243, item 1623 with subsequent amendments [1].

2. Environmental criteria

The European Commission has taken action to develop a common criteria for Green Public Procurement which can be used in European Union Member States. The advantage of common GPP criteria is to prevent restrictions of competition, which could arise as a result of the diversification of national criteria.

GPP criteria (environmental criteria) have been developed for these product groups, which were considered most suitable for the implementation of GPP (Green Public Procurement), both because of the value of the contracts and the impact on the environment [10].

Construction is one of the sectors for which a common criteria was developed (including raw materials, such as wood, aluminum, steel, concrete, glass, and building products such as windows, wall and floor coverings, heating and cooling equipment, aspects related to maintenance of buildings, execution of works contracts in place).

Environmental criteria is proposed for each of the stages of the construction project, such as the design stage, construction, operation and decommissioning of buildings.

Environmental criteria relates to energy consumption, the use of renewable energy sources (RES), construction materials and products, waste and water management as well as other aspects influencing the environmental impact of construction: architects' experience, monitoring and user aspects. Green Public Procurement should consider the overall environmental profile of the entire building.

The criteria can be used in tenders for the construction of new buildings, as well as in relation to contracts for repair and maintenance. This criteria should be directly connected to the tender documentation and include information on the methods of verification [6].

The term "environmental criteria" "includes not only the selection criteria and award of the contract, but also specifications and clauses of the contract. For each product/service group two sets of criteria are presented [6]:

– Basic GPP criteria addresses the most significant environmental impacts and can be used with minimum additional verification effort and cost increases; – Comprehensive GPP criteria are intended for use by institutions that are trying to purchase the best environmental products available on the market, and may involve additional administrative effort or entail some increase in cost compared to other products performing the same functions.

In order to increase the degree of integration of environmental considerations in procurement procedures, EU GPP criteria have been translated into Polish for selected product groups or sectors, including for construction.

Another sources of GPP criteria are eco labels. Eco labels exist for a variety of construction materials and products. Even though contracting authorities cannot require purchased products bear a specific eco label, the environmental criteria underlying an eco labelling scheme can provide valuable assistance in developing environmental criteria and the labels themselves constitute easy ways of demonstrating compliance with those criteria [3].

In the case of energy certificates awarded to buildings currently in Poland, the certification process can be carried out in the British system, BREEAM International Bespoke awarded by the organization BRE Global (Building Research Establishment) and the American LEED (Leadership in Energy and Enviromental Design). Up to March 2010 in Poland 20 LEED certified projects, including one LEED-NC v.2.2 at the level of silver as well as 9 – BREEAM systems were registered. [9]

The contracting authority may take environmental issues into account by determining specific evaluation criteria or conditions for participation in the proceedings in the tender documentation.

An ecological evaluation criterion carried out by the contracting authority is not sufficient. The contracting authority has the additional task to take care of its measurability, define how to assess an offer based on the criteria and assign a certain validity. Among the ecological evaluation criteria most frequently mentioned: use of the best available technologies in the field of environmental impact, operating cost, product life-cycle costs (LCC), the technical quality of the proposed solutions, the level of emissions, noise and water consumption, power consumption, etc.

In the case of “green procurement” in building, environmental criteria may also relate to the use of construction products with a minimum use of energy for their manufacture and eventual disposal, or products that can be recycled or are biodegradable, as well as the criterion of efficiency

The contracting authority may also specify notice and tender documents in the contract, as well as how many additional points will be awarded for each award criterion. Where the award criterion is formulated in terms of “better performance compared with the minimum requirements set out in the technical specifications”, points will be awarded in proportion to the improved results.

3. Environmental criteria in Public Procurement for works

The Public Procurement Office prepares the documents, on the basis of which are realized information and training for representatives of the contracting authorities, aimed at popularizing the integration of environmental considerations in Public Procurement. The National Action Plan [8] on sustainable Public Procurement for the period 2013–2016 is already the third planning document which includes results of the monitoring process for granting green procurement, including in the construction sector. The Public Procurement

Office conducts periodic analysis of the degree of greening procurement based on a representative sample of contract notices on the basis of its own methodology. The analysis takes the notice published in the Public Procurement Bulletin and published in the Official Journal of the European Union into account. Table 1 presents results of monitoring conducted by the Public Procurement Office in the period 2006–2012 demonstrating the scope of green procurement.

Table 1

The percentage of green procurement in the total number of procedures, on the basis of [8]

Year	Total percentage of green procurement	Percentage of green procurement in the proceedings of values below EU thresholds	Percentage of green procurement in proceedings of the value above EU thresholds	Total value of green procurement (mld zł)
2006	4.00%	No data	No data	3,18
2009	10.50%	No data	No data	13,30
2010	9.00%	7.04%	11.16%	16,80
2011	12.00%	8.00%	15.00%	18,82
2012	12.00%	9.50%	14.50%	15,90
Plan for 2016	20%			

In the analyzed period, a moderate increase in the degree of integration of environmental aspects in procedures for the award of public contracts can be noted , which is a result of a growing interest in environmental issues on the part of authorities. The number of orders taking environmental aspects in Poland into account is lower than that assumed by the Public Procurement Office and one of the lowest in the EU.

4. Construction works

According to the tender procedures examined in 2009–2010 in the construction sector, it was determined that the percentage of orders which consider certain environmental criteria is 25% (Fig. 1). The environmental criteria used was related to e.g. the level of water consumption used by equipment, using the best technology in the field of environmental impact in the construction of sewage treatment plants and wastewater regulation, modernization of buildings (ie replacement of window frames, insulation of the building), reconstruction of water supply and sewerage (eg installation of compressor stations, sewage pumping stations, etc.) [8].

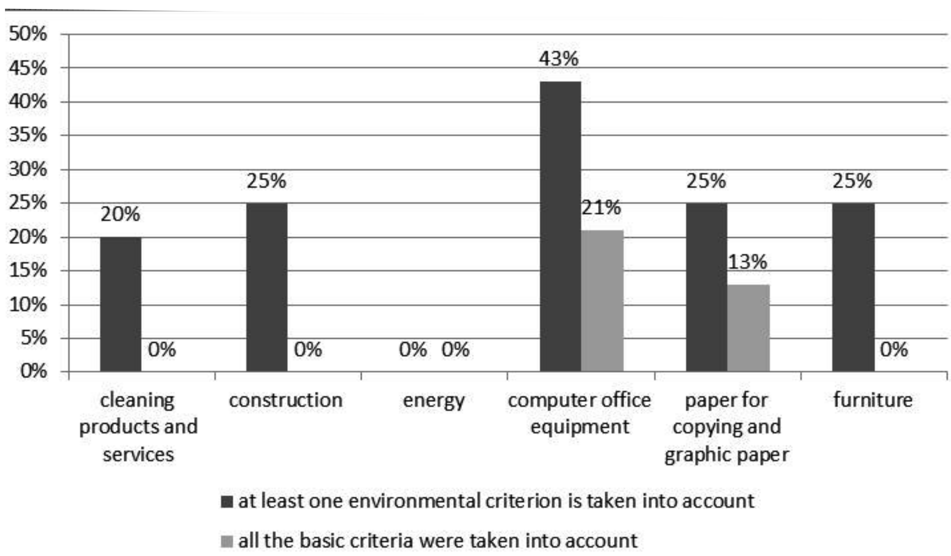

Fig. 1. The percentage of Green Public Procurement in Poland [8]

5. Conclusions

Green procurement can provide purchasing savings throughout the life cycle of the building. The practice of public procurement in Poland shows that contracting authorities focused rather on purchase price of construction works than on the future operating costs generated during the use of buildings.

In Poland, the use of environmental criteria in Public Procurement procedures for construction is not very low but still insufficient.

According to the Public Procurement Office, the application of environmental criteria (with some exceptions) by contracting authorities and the lack of expertise knowledge regarding technical specifications is a factor which effectively inhibits growth of the environmental dimension of Public Procurement. The Public Procurement Office indicates that some action should be taken, such as: increasing awareness of GPP through a system of training, increasing the number of operators who hold a verified system environmental management (EMS), (such as EMAS or ISO 14001:2005), increasing the number of national EU Ecolabel certified products and national eco-labels according to ISO standards.

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TECHNICAL TRANSACTIONS | **CZASOPISMO TECHNICZNE**
CIVIL ENGINEERING | BUDOWNICTWO

2-B/2014

PAWEŁ SZYMAŃSKI, BLANKA WINIECKA-KOWALCZYK, PIOTR NOWOTARSKI*

MULTI-CRITERIA CERTIFICATION OF BUILDINGS IN POLAND

CERTYFIKACJA WIELOKRYTERIALNA OBIEKTÓW BUDOWLANYCH W POLSCE

Abstract

The certification of green buildings has become more and more popular as a tool used for comparison and evaluation of newly built structures. The authors of this article analyse various certification systems of green buildings in Poland with particular interest paid to newly built multi- and one-family residential buildings. The reason there is such little interest in green building certification processes is also considered. Additionally, the major constraints behind introducing green building certificates for newly built structures is also presented. The Article also presents an analysis of benefits resulting from green building certification for investors, contractors and final users of a particular building.

Keywords: Green buildings, green building certification, LEED, BREEAM, DGNB

Streszczenie

Certyfikacja budynków ekologicznych staje się coraz popularniejszym narzędziem dla porównania i oceny nowo powstających obiektów. W artykule dokonuje się analizy dostępnych w Polsce systemów certyfikacji ekologicznej budynków ze zwróceniem uwagi na powstające obiekty mieszkalne zarówno wielorodzinne, jak i jednorodzinne. Rozważa się przyczyny małego zainteresowania procesem certyfikowania oraz prezentuje największe przeszkody w wprowadzaniu ekologicznych certyfikatów dla nowo budowanych obiektów. W artykule przeprowadzono także analizę korzyści wynikających z certyfikacji obiektu dla inwestora, wykonawcy i użytkownika końcowego obiektu.

Słowa kluczowe: Zielone budynki, certyfikacja ekologiczna, LEED, BREEAM, DGNB

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1. Introduction

Nowadays, in the era of the development of building construction, the main field of interest in the context of both old and newly built structures is ecology, economy and societal needs. New solutions, which allow one to live in a healthy, convenient and low-cost building, are being pursued. Taking sustainable development into consideration, appropriate certificates have been created allowing for the evaluation and comparison of buildings in this respect. The umbrella term of green building certification, which encompasses such certification systems associated with energy sustainability as LEED, BREEAM and DGNB, is commonly used in Poland. It should be remembered that these terms and systems are actually multi-criteria evaluation methods for structures which provide a broader perspective on a particular building.

The history of certification begins at the end of the 20th century. A report by the World Commission on Environment and Development entitled “Our Common Future” defines the term “sustainable development”. Sustainable development „fulfills the needs of the present without compromising the ability of future generations to meet their own needs. In the broadest possible meaning, the strategy of sustainable development is aimed towards nurturing harmony between humanity and environment” [1]. While analysing the need for sustainable building construction, the main focus being on the following:
– limiting climate changes,
– environmental protection,
– better natural resource management,
– health protection,
– high quality of life,
– social integration,
– limiting costs of building exploitation.

The points listed above have led to the creation of a multi-criteria certification that has been developing for the past decade and which has resulted in systems for evaluating the quality of a particular building depending on the criterion applied.

2. The most popular certification systems used in Poland.

Green building certification has been quite recently introduced in Poland, however, it becomes more and more popular when it comes to newly built structures. The most popular certificate is the so-called LEED. The Leadership in Energy and Environmental Design, which was developed in the United States of America in 1998 by an American organization – the U.S Green Building Council that deals with green building standards. LEED is one of the most popular certificates in the world. It is mainly issued in the United States of America (one-third of all LEED-certified structures in the world).

Structures, which meet the criteria for certification, may also be encountered in other highly developed countries.

Depending on the structure type, the following LEED certificate types may be distinguished:
– LEED for New Construction,
– LEED for Homes,

– LEED for School,
– LEED for Core& Shell,
– LEED for Retail,
– LEED for Commercial Interiors,
– LEED for Existing Buildings,
– LEED for Neighborhood Development.

Certification consists of seven criterion groups regardless of the type chosen [2]. Altogether there are 110 points to earn from all categories. However, the most important part is an obligatory fulfillment of prerequisites. Should any of the prerequisites not be fulfilled, a certificate will not be granted. Certification consists of the following categories: sustainable sites (max. 26 points), water efficiency (max. 10 points), energy and atmosphere (max. 35 points), materials and resources (max. 14 points), indoor environmental quality (max. 15 points), innovation in design (max. 6 points, including 1 point for the presence of a LEED consultant), regional priority (max. 4 points). The first five groups consist of these prerequisites. If the total score is between 26 and 32 points, it allows for basic certification. The number of points a particular project earns determines its level of LEED certification:
– Certified – 40–49 points,
– Silver – 50–59 points,
– Gold – 60–79 points,
– Platinum – 80 points and more.

Usually, the LEED system is handled by trained consultants. In order to become a consultant, one must have professional experience within the green building industry, participate in a course and pass two exams. The first exam is a basic LEED GA (Green Associate) exam followed by LEED AP exam, however, the latter one may only be taken if one has documented their engagement in projects connected with LEED certification.

In order to acquire a certificate, one must hire a consultant that will help an investment and obtain and realize the highest possible score. A decision to acquire a certificate should be gained as early as possible, preferably at the design stage, as one's late decision may impede the fulfillment of the prerequisites for certificate acquisition.

Yet another certificate issued in Poland is the so-called BREEAM certificate [3]. The Building Research Establishment Environmental Assessment Methodology, which was developed by a British organization – BRE (Building Research Establishment) in 1990. [4] All newly built and restored buildings in the United Kingdom will be required to have BREEAM certificate from 2019.

Depending on the building type, the following BREEAM certificate types may be distinguished:
– BREEAM Domestic,
– BREEAM EcoHomes,
– BREEAM EcoHomes XB,
– BREEAM Multi-Residential.

Additionally, depending on the building functions, the following BREEAM certificate types may be distinguished:
– BREEAM Offices,
– BREEAM Education,
– BREEAM Courts,
– BREEAM Prisons,

– BREEAM Retail,
– BREEAM Healthcare,
– BREEAM Industrial.

A BREEAM certificate is based on eight criterion groups: Management (12% of the total score), Health and Wellbeing (15%), Energy (19%), Transport (8%), Water (6%), Materials (12,5%), Waste (7,5%), Pollution (10%) and Innovation (10%)

The percentage of points a particular project earns determines its level of certification [5]:

PASS – 30–44%, GOOD – 45–54%, VERY GOOD – 55–74%, EXCELLENT – 75–84%, OUTSTANDING – 85% and more.

Similarly to the LEED certification process, in order to acquire BREEAM certificate, one must hire specialists called "assessors". An assessor is a mediator between an investor and certification body. In order to become an assessor, one must only participate in a three-day course and pass an exam. At the next step, a candidate is required to deliver a case study that will be evaluated within three months from the date the candidate passed their exam. Candidates are not required to have professional experience within the green building industry. An application for BREEAM certificate must be filed within 12 months from the commencement of building occupancy.

The last certificate being analysed in this paper is the so-called DGBN certificate. Deutsche Gesellschaft fur Nachhaltiges Bauen certificate, which was developed by the German Society for Sustainable Building. It is the most exacting and, at the same, the most transparent multi-criteria system used for building evaluation. It consists of only two prerequisites which are quite difficult to fulfill. The first prerequisite concerns the total amount indoor VOCs (Volatile organic compounds) in chosen rooms. The total VOCs concentration must not exceed 3000 $\mu g/m^3$ while the amount of formaldehyde must not exceed 120 $\mu g/m^3$. Additionally, buildings must be adapted for the disabled in all public areas.

DGNB Certification is comprised of the following aspects: [6]: ecological, economic, socio-cultural, technological, process quality and location. Owing to universal criteria, the certificate may be issued for all types of structures. The following certificates can be acquired [7]: Bronze (>50%), Silver(>65%) and Gold (>80%).

There are two advisers for the purpose of certification process: a Consultant and an Auditor. In order to become an advisor, one must pass a series of tests and prove to have a year-long professional experience and education within the building construction industry.

3. The use of certificates in Poland

Polish Investors more frequently apply for green building certificates to enhance the prestige of a particular structure and highlight its uniqueness. The most popular certificate is the aforementioned LEED certificate. So far, the certificate has been granted to the total of 19 buildings, including 5 at the highest Platinum level. The second most popular certificate is BREEAM certificate. It is easier to obtain, hence it may be issued more frequently in the coming years. It is said that DGNB certificate, in turn, is the most difficult one to be obtained. However, any building that has achieved DGNB certificate is deemed to fulfill the strictest requirements. The DGNB certificate is the only certificate that encompasses facilities for the disabled and this, undoubtedly, increases its value.

Each certificate focuses on different aspects, yet all of them encompass the same scope: cost-effectiveness and energy sustainability. Hence, the use of green building certificates will become yet another tool used to enhance convenience, elegance, energy sustainability, greenness and prestige of buildings surrounding us in the upcoming decades.

Table 1

The comparison between LEED, BREEAM and DGNB certificates

Comparison criterion	LEED	BREEAM	DGNB
Certification body	USGBC	BRE	DGBN
Number of certification levels	4	5	3
Number of prerequisites	8	11	2
Maximum score	110 points	100%	100%
Minimum score required for certification	40 points	30%	50%
Presence of specialists	Consultant (non-compulsory)	Assessor (compulsory)	DGNB Consultant DGNB Auditor
Number of certificates issued in Poland (until the end 2013)	19	6	No data is present

4. Benefits of green building certificate acquisition

Green building certification offers multiple benefits at particular stages of building functioning starting from its construction and through to its final use. The following participants of a construction process should be distinguished: a constructor, an investor and a final user, each of whom derives different benefits from building certification.

From the contractor's perspective, entirely new technologies of building connected with cost-effectiveness and sustainable construction seem most appealing [8]. Every constructor employed in the construction of buildings qualifying for certification derives such benefits as knowledge of the newest solutions within the field of technology, ecology and energy sustainability. This, in turn, enhances the prestige of a particular entrepreneur. Having a portfolio, which includes certified and modern buildings, one may easily compete to be contracted for realization of much bolder investments. Moreover, one's knowledge of sustainable construction may become crucial for potential investors when choosing a contractor. It is also highly probable that higher remuneration for realization of construction works will be offered to those constructors, who may guarantee that a particular construction element will be made in a proper way as well as in accordance with the best construction practices and manufacture's requirements. It is also worth mentioning that one should not mistake a new building for a modern building complying with all requirements concerning energy sustainability. Modern and innovative solutions, which are indispensable while constructing buildings that qualify for an appropriately high level of certification, are considered to be a particular contractor's „know-how". Besides, such new solutions and ideas may be used by the contractor during realization of subsequent investments and for enhancing its competitiveness and reliability in the eyes of potential investors.

Any investor, who decides to invest in a building which complies with current requirements of certification programmes, also benefits. In the case of a commercial building, the number of potential clients increases significantly. Companies, in particular large international corporations relocating their offices to Eastern Europe, including Poland, tend to choose green, sustainable and original buildings such as the Green Towers building in Wrocław built by Skanska. It is the first structure in Poland that has been granted with the highest level of LEED certification, i.e. Platinum. The investor had no difficulties in finding lessees by offering commercial space in a modern building that complies with the world's highest green standards prevailing within the construction industry. Ernst & Young, Grupa Allegro, Dolby, Grupa Medicover, Becton Dickinson, Nokia Siemens Networks and Talex are, among others, the most recognizable lessees of the aforesaid building [9].

Finally, final users receive a modern and sustainable building of low exploitation costs such as heating costs, which comprise the greater part of all expenses for the building exploitation. Additionally, they acquire prestige, quality, and durability guaranteed by a particular certificate. Obviously, the costs of building maintenance depend on the way a particular building is being exploited. Some certification systems bind users of a particular building by separate agreements to use it in the most cost-effective and energy sustainable manner by using appropriate devices, which guarantee low energy consumption as well as by complying with all requirements imposed by a certification body that concern indoor area development. In return, the users are guaranteed that the building will comply with all relevant requirements and sustain high quality standards while being exploited. It should also be mentioned that from a lessee's perspective, where a lessee is usually a company that makes every effort to keep its profile high, the choice of a green building becomes a feature that distinguishes the said company from its competitors. Well-known brands and large corporations pay significant attention to PR activities, including the choice of a proper company's seat. A Green and Energy Sustainable image becomes an indisputable and desirable quality for an entrepreneur.

5. Issues and constraints on accessing green building certification and multi-criteria evaluation of buildings in Poland

Neither multi-criteria evaluations of buildings nor green building certifications are commonly used in Poland. There are several reasons for such low popularity of the aforesaid solutions. Fig. 1 shows the most important, according to the authors, reasons for such low interest in green building certification.

The major constraint on building certification is additional construction costs [10]. These costs include not only certification costs but also, in the case of constructing a building that is subject to multi-criteria evaluation, the cost of green materials and appropriate solutions. The following add to the construction costs of certified buildings: use of modern materials of sufficient quality in order to ensure minimum heat losses, use of modern technologies and solutions regarding ventilation and air-conditioning as well as other factors that influence the entirety of a building, convenience in using it as well as its operating environment. The aforementioned costs are directly proportional to the cubature and purpose of a building. This aspect is often emphasized by those who are interested in green building certification. Nevertheless, it should be highlighted that investments in modern technologies only bring profit during the exploitation of a building. As far as heat used to keep a particular building warm as well as the use of electricity and other utilities taken into consideration, higher initial costs bring real profits during exploitation. Despite that, the same higher initial costs may become a serious constraint for entities that have a fixed budget during the construction phase.

Fig. 1. The main reasons for low interest in Green building certification in Poland

Nowadays, social environmental awareness in Poland is much higher than it used to be. It can be observed that ecological aspects of all areas of life such as nutrition, leisure and professional activities, attract more and more attention. Despite the fact that people spend most of their life time indoors and should therefore care about buildings as well as their life environments, green building certificates issued as part of multi-criteria evaluation of buildings are not very popular. This situation is changing very slowly due to lack of both social campaigns and relevant advertising campaigns. It is anticipated that the demand for certified green buildings in Poland will rise, though. The higher social environmental awareness in Poland is, the faster the demand increases.

The lack of social and environmental awareness is also connected with the lack of generally available and accurate information about certification systems in Poland, as well as the certificates themselves. Many contractors and investors know that there are such certificates yet they do not have detailed information about them. This, in turn, constitutes a serious constraint on wide use of certification as potentially interested parties give up on it precisely due to lack of information. Additionally, final users, being unaware, very rarely require information from contractors that buildings comply with the newest green standards.

It can therefore be said that investors, contractors and final users are caught in a vicious circle that can only be broken by tapping sources of information about multi-criteria evaluation and green building certification.

Certification procedures take some of the time one needs to complete all necessary formalities and this constitutes yet another constraint on the general use of certificates. In order to obtain a certificate, one must undertake additional actions, i.e. apply for material checks as well as for particular stages of the construction process to be inspected. It happens quite often that Investors as well as Contractors do not approve of these additional duties and decide not to apply for a certificate despite all the benefits it carries.

In the case of LEED certificate, there is one additional constraint, i.e. periodical inspections of a building carried out to sustain the level guaranteed by the certificate. This duty belongs to final users of a building who should make every effort to ensure that a particular building is used accordingly to its purpose and does not lose its certification status. Such a duty should be imposed on users of all buildings regardless of their certification status or even a lack of it. Unfortunately, it can be observed that due to poor property management and improper exploitation, both technical and visual conditions of many buildings worsen. This, in turn, is reflected in higher exploitation costs and may cause additional restoration expenses.

5. Conclusions

The analysis of the most popular systems of multi-criteria evaluation of buildings in Poland shows that there are multiple systems and centers for building certification. Each of them evaluates different aspects of buildings yet all of them encompass the same scope: cost-effectiveness and energy sustainability. Some systems (e.g. LEED) encompass criteria that require an administrator as well as final users of a particular building to take care of the building during its lifetime, which, consequently, has a positive effect on the building's condition.

It can be said that major constraints on general and wide use of multi-criteria evaluation of buildings are both social awareness and ecological sensitivity that develop only through access to information and knowledge about modern technologies and solutions used within the construction industry. Certification costs should always be calculated keeping future savings in utilities costs in mind, which can be achieved through investments in modern technologies at both design and construction stages.

Multiple benefits of green building certification, which can be enjoyed by all individuals engaged in designing, constructing and exploiting a particular building, should not be omitted. It is certain that every certified building has been assiduously constructed and has a guaranteed level of energy efficiency, which, in turn, brings benefits not only to final users but also for constructors, who are proud to have knowledge about the newest technologies as well as the "know–how" on how to properly produce and provide ecological solutions within the construction industry.

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EXECUTION OF CONSTRUCTION WORKS

REALIZACJA ROBÓT BUDOWLANYCH

TECHNICAL TRANSACTIONS | **CZASOPISMO TECHNICZNE**
CIVIL ENGINEERING | BUDOWNICTWO

2-B/2014

AGATA CZARNIGOWSKA*, ZBIGNIEW TOKARSKI**

ASPHALT-AGGREGATE MIX HANDLING PROCESS OF POROUS PAVEMENT REHABILITATION PROJECT

ANALIZA PROCESU DOSTAW MIESZANKI MINERALNO--ASFALTOWEJ PRZY REKONSTRUKCJI NAWIERZCHNI Z ASFALTU POROWATEGO

Abstract

The paper presents a case study of an innovative method of porous pavement rehabilitation works. The innovation consists in applying an additional piece of plant to collect the supplied asphalt-aggregate mix and feed it pavers. Observations and measurements of construction process output collected during an A73 highway rehabilitation project in the Netherlands can be used for creation of asphalt-aggregate mix supply models and comparing efficiency of using certain plant sets.

Keywords: pavement rehabilitation, porous asphalt, highway, process innovation

Streszczenie

Artykuł prezentuje zastosowanie innowacyjnej metody organizacji robót przy wymianie warstwy ścieralnej nawierzchni autostrady z asfaltu porowatego. Innowacyjność rozwiązania polega na zastosowaniu dodatkowych podajników mieszanki mineralno-asfaltowej. Przedstawiono wyniki obserwacji i pomiarów dokonanych w czasie robót na autostradzie A73 w Holandii. Wyniki pomiarów mogą posłużyć do budowy modelu dostaw mieszanki i porównań efektywności stosowania różnych zestawów maszyn.

Słowa kluczowe: rehabilitacja nawierzchni, asfalt porowaty, autostrada, innowacja procesowa

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1. Introduction

The European road transport infrastructure is currently in the state of rapid development (as in Poland and other "new" EU members) or rehabilitation and reconstruction. Polish highways are predominantly constructed using well established methods and materials. The works are conducted by means of traditional methods with typical plant sets of trucks and pavers, and traditional approach to work organization and logistics. However, new materials are being developed and more economical structures are being tested. Soon there will be a need for designing efficient construction processes (and selecting plant sets) related with application of these new materials. Observing the Polish highway construction sites one may have an impression that while the pavers are usually modern and cutting-edge technology, the means of transport tend to be time-worn and thus more prone to failure. This however changes as contractors replace their fleets in answer to recent high demand for their services. Modern plant is but a part of a project success. This was demonstrated by some spectacular failures in terms of project management, knowledge, and experience.

Polish highways are quite new, but massive rehabilitation works will have to be conducted sooner or later, and to assure their smooth execution, work planning should be based on real-life data. These may be gathered by observing works conducted in other countries. The Netherlands are one of the Europe's leaders in all aspects of road infrastructure planning, construction and maintenance innovation [2, 6]. The Netherlands' subsoil conditions are particularly unfavorable, and the lack of natural aggregates implies that construction material reclamation stays the focus of each project [13]. This is one of the "natural" causes of searching for new efficient materials and techniques. Moreover, the Dutch highways are already "mature" structures, and their wearing courses reach now the end of service and need to be replaced. Thus, the rehabilitation projects (using modern materials and plant) are run on a large scale. The experience of Dutch contractors, and their willingness to share it [14], was the basis of this paper.

2. Sustainable development in road construction

A road's lifecycle comprises four basic phases: programming and design, construction, operation and maintenance, and decommissioning. A project's objective function is, naturally, case-specific. Traditionally, it is minimizing construction time span (so reducing construction-related inconvenience to the public and improving the picture of public sector efficiency – important for political reasons), minimizing cost (so lowest bid procurement), and maximizing durability of the delivered infrastructure (so preference for proven, usually raw material-intensive solutions); whereas the product stays fit for purpose. Nevertheless, there are other objectives whose growing importance is reflected in the development in EU policies [9]. These are minimizing impact on the broadly understood environment, improving user safety, and reducing life cycle costs. These aims cannot be reached without careful planning in the initial stages of project preparation [6]. The need to turn to the sustainable development works its way to Polish road infrastructure. Utilization of reclaimed material and waste is being investigated into and more and more often reaches prototype stage [12], and public clients invest in research and development projects. One of the main aims is to provide the society with low-energy-consuming, pollutant emission-free, safe, durable and affordable pavements. It becomes important that they could be obtainable with less non-renewable resources. Thus, living conditions and resource-use meets current needs without undermining the sustainability of natural systems and the environment, so that future generations may also have their needs met – which is the underlying idea of sustainable development [4].

3. Porous asphalt

Porous asphalt is one of the relatively recent and promising inventions in the field of pavement materials. According to PN-EN 13108-7 standard [11], it is defined as a mineral-asphalt mixture designed in a way that provides large content of interconnected voids that allow for air and water flow through the material. To improve mechanical properties of the material, small quantities of organic or inorganic fibers can be added to the mix. The porous asphalt's origins are in nineteen-seventies in the USA. As the tests on trial sections were promising, the technology has spread throughout most European countries and Japan [10]. Porous asphalt seems to answer the requirements for a perfect wearing course – with a high content of coarse-grain fraction the structure does not deform under traffic loads, and the surface is rough, which improves safety. Due to rainwater being quickly removed from the surface, there is no aquaplaning, and glare in the nighttime is reduced. Also the traffic noise-reduction qualities cause growing interest in this type of wearing courses (e.g. [1, 5, 16]. Figure 1 compares the sound absorption properties of porous pavements of varying void content, illustrating to what extent the mix design can affect noise properties.

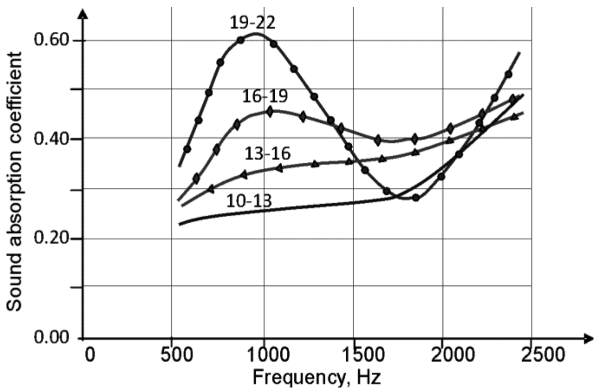

Fig. 1. Efficiency of sound absorption vs. sound frequency according to void contents in porous asphalt pavements. Based on [16]

The material cannot be designed without careful consideration of local conditions, so there is no possibility of a direct country-to country transfer of experiences [8]. The Polish research community interest in this technology dates to early nineteen-nineties and is growing – in terms of material science [12] and construction methods [15]). There exist related standards

[11] and recommendations [17], but practical applications are still limited to trial sections [7]. It is to be expected that a material with a large content of open pores is potentially more vulnerable to environmental and traffic loads, and its service life can be shorter that of traditional materials. The condition of the wearing course of porous asphalt deteriorates over time, so the noise absorption and other advantages of the material may be lost. The long-term impact of high and low temperatures, clogging with dust and traffic-related abrasion on the properties of porous asphalt structure are being vigorously investigated into all over the world (e.g. [1, 3, 5]) to verify the rather optimistic observations of its long service life. The reasonable service life of a wearing course is understood as the period of service life with the qualities of the surface staying on the declared level. Draining properties of porous asphalt are measured by coefficients of horizontal and vertical permeability (K_h, K_v) and are defined by requirements towards voids content (V_{min} and V_{max}) related with aggregate gradation. Water sensitivity is related with the category of indirect tensile stress ratio (ITSR). To determine the condition of the wearing course one measures particle loss (PL). As the wearing course loses its properties, it needs to be replaced.

4. Case study: Rehabilitation of A73 highway section in the Netherlands

4.1. Project background

The surface of A73 highway section being the object of the analysis was completed in 1997, and by 2013 it was subject only to routine and preventive maintenance, with local repairs of the wearing course. The structural design (Fig. 2) was based on Dutch standards on semi-rigid and rigid pavements. The road section is shown in Fig. 3.

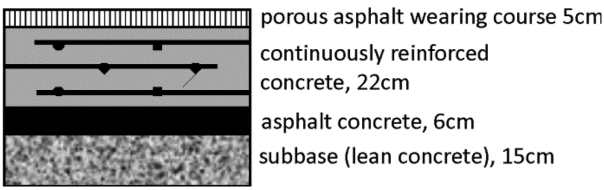

Fig. 2. Structure of the A73 highway pavement

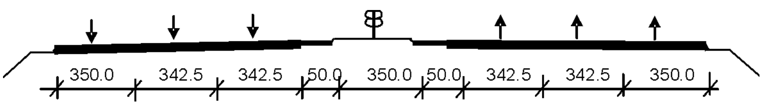

Fig. 3. Cross-section of the A73 highway

The continuously reinforced concrete layer of the A73 lanes was constructed in 1993-1997. The longitudal joints were executed as the concrete was placed and floated. Fig. 4a and Fig. 4b present the type of machinery used in this process: a portable concrete batching plant MOB 60 and concrete paver CAT SF350.

The original porous asphalt overlay was placed in a traditional way, by means of a machine set composed of one/three pavers served by trucks. Fig. 5 presents the works.

In September 2013, the wearing course had to be replaced in the A73 section between the towns of Venray and Venlo (Fig. 6). The traffic was completely closed in one carriageway of the whole section. However, the time window allowed for the works was between Friday, 8:00 p.m. and Monday, 6:00 a.m. (on weekends the traffic is considerably lower as no freight vehicles are allowed to travel; and car detours are easier to plan). Therefore, one of the objectives was to complete the works as soon as possible. To speed up the works, an innovative method was used: the pavers were equipped with additional feeders with receiving hoppers able to hold 10 Mg of the mix. The feeders were intended to make mix unloading easier and to protect the workflow from disruption caused by material delivery delays. This way, the pavement quality standards are easier to be met, and the environment is less affected by the construction-related emissions. Fig. 7 presents the machine set used on site.

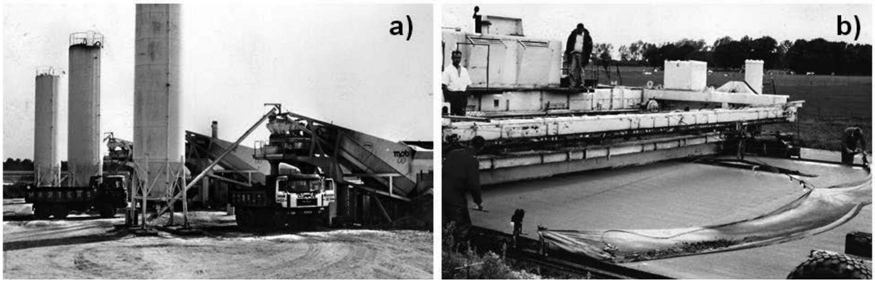

Fig. 4. Construction of concrete layer (1997): a) concrete batching plant, b) placing concrete (source: Z. Tokarski)

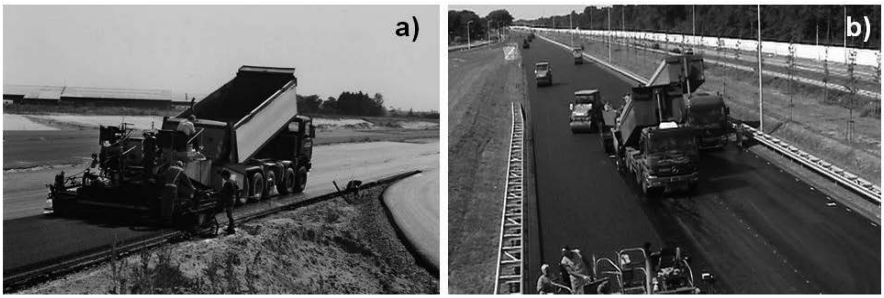

Fig. 5. Placing the original porous asphalt course (1997): a) one paver, b) three paver set (source: Z. Tokarski)

4.2. Rehabilitation works and on-site observations

The rehabilitation works in 2013 were planned with the assumption of continuity of works – and continuity of supplying the site with the mix. Therefore, the plant sets had to be selected with the utmost care. Actual quantity of material delivered by the trucks was determined at the asphalt batching plant on the basis of the plant's scales readings. The results (selected), together with average values and sample standard deviations are presented in Table 1, according to the type of truck. The analysed works were supplied by means of 4-, 5- and 6-axle dump trucks. Trucks of the same axle number were equipped with the same capacity of the box. Actual unloading rates of the trucks supplying the MT-3000-2 Vögele mix feeders are presented in Table 2 (selected measurements).

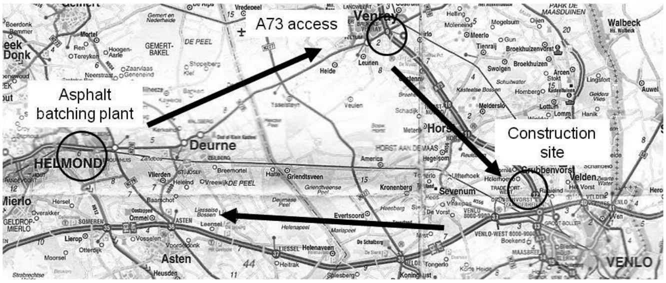

Fig. 6. Location of the works (2013)

Fig. 7. Resurfacing: machine set of paver, feeder and truck at work (2013) (source: Z. Tokarski)

Table 1

Quantity of asphalt mix loaded on consecutive trucks of each size

No.	Mix quantity on truck, kg		
	6-axial	5-axial	4-axial
1.	32700	28380	25680
2.	33260	29880	25280
3.	33680	28340	25460
4.	32180	29120	25240
5.	33020	30080	25660
6.	33720	29680	22040
...	...	...	...
Average	32638	29341	24198
Std. dev. (sample)	1458	692	1776

Table 2

Truck unloading rates

No.	Arrival	Departure	Axle number	Truck ID	Mix quantity, Mg	Unloading rate, Mg/min
1.	11:59:00	12:03:35	5	BL-RJ-84	28.320	6.179
2.	12:13:50	12:18:26	5	BX-RR-66	29.120	6.330
3.	12:44:20	12:48:40	5	BV-HB-54	30.060	6.937
4.	12:50:30	12:54:12	6	BL-ZX-41	29.940	8.092
5.	13:09:43	13:13:15	6	BS-NF-85	31.560	8.932
6.	13:13:46	13:17:45	5	BS-XZ-20	30.160	7.571
7.	13:23:00	13:27:00	5	BR-SZ-39	29.880	7.470

Measurements taken on site by courtesy of the contractor allowed the authors to assess the actual average capacities of the plant and their distribution parameters, so to collect input for constructing models of construction processes planned in the future. The data were collected with the aim of comparing them with measurements taken during other projects with different work organization and different plant. Having recorded e.g. the unloading time, one can calculate the rate of feeding the mix from the feeder to the paver or assess the scale of advantage on using feeders. There are a relationship between the quantity of transported mix, unloading time and feeder output. 6-axle trucks are naturally most productive, but due to their size their maneuvering time is longer, and so is their work cycle – only on-site measurements allow the planners to asses consequences of selecting trucks of certain sizes. The measurements in the asphalt batching plant provide data for estimating material flow to the construction site even if truck sizes are various, and arrivals sequence is random. The truck-by-truck measurements help determine distribution parameters of time and output of particular operations, and frequencies and scale of disturbances. With such input, models of construction processes can be more accurate, which is important in planning projects with extremely short time spans and usually high contract penalties.

5. Conclusions and further research

The conclusions from the observation of the works and on-site measurement is that one of the key success factor of high-speed repaving works is controlling the supplies. Discontinuity of supplies causes work stoppage, and this affects quality of the product. The decision variables (such as truck capacities and number, mix placing methods) and independent variables are numerous and subject to uncertainty. On-site measurements provide input for planning future works. They are the basis for decision on selecting most suitable plant sets to reduce idle time at reasonable work stoppage risk: in the presented project, the contractor decided to use additional feeders, not necessary from the point of the effect of the works, and related with additional cost – to assure that the pavers receive the mix continuously, and to speed up truck unloading process. Future work is aimed as using the data for constructing queuing models and simulation models considering the progress of the works and changing distance between the batching plant and the construction site.

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TECHNICAL TRANSACTIONS | **CZASOPISMO TECHNICZNE**
CIVIL ENGINEERING | BUDOWNICTWO

2-B/2014

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SELECTED ISSUES CONCERNING RECONSTRUCTION OF THE PALACE COMPLEX IN GORZANOW

WYBRANE ZAGADNIENIA REKONSTRUKCJI ZESPOŁU PAŁACOWEGO W GORZANOWIE

A b s t r a c t

The paper discusses an assessment of the technical condition of the historic Palace Complex in Gorzanow, and the reasons behind the damage incurred to its structure. The research has been carried out by the authors. The article presents the scope of implemented repair work intended to secure the building against further degradation, as well as a work plan that would make it possible to fully reconstruct the most valuable qualities of the palace in Gorzanow. The primary focus of the article has been applied to technical and organisational issues, regarding an ambitious endeavour to restore the building in question to full functionality and serviceability.

Keywords: Repairing of a historic building, assessment of technical condition, assessment of building structures

S t r e s z c z e n i e

W artykule przedstawiono wykonaną przez autorów ocenę stanu technicznego omawianego obiektu o charakterze zabytkowym oraz przyczyny powstałych w nim uszkodzeń. Przedstawiono także zakres przeprowadzonych prac naprawczych zabezpieczających obiekt przed jego dalszą degradacją i program prac umożliwiających pełną rekonstrukcję najcenniejszych walorów pałacu w Gorzanowie. W pracy skupiono się na problemach technicznych i organizacyjnych związanych z realizacją ambitnego przedsięwzięcia, jakim jest doprowadzenie omawianego obiektu do pełnej funkcjonalności i użytkowalności.

Słowa kluczowe: Remont obiektu zabytkowego, problemy remontowe, ocena stanu technicznego, diagnostyka konstrukcji budowlanych

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1. Introduction

Historic palace complexes are an inherent part of the landscape of Lower Silesia. However, in recent decades many of them have succumbed to slow degradation and lost their artistic qualities. This is often due to a lack of regulated proprietary rights and the need to frequently implement large scale modernisation works, in order to restore such a building to serviceability [1]. The palace complex in Gorzanow has experienced a similar situation, as the lack of proper protection and failure to carry out necessary modernisation work has resulted in a construction disaster. The building in question has undergone frequent changes in ownership and the lack of ongoing repairs led to many permanent defects in structural elements, but above all, degradation of the magnificent decorations, ornaments, and architectural details.

2. Assessment of the technical condition

Assessment of the current technical condition constitutes the basis for designing all necessary reinforcements, repairs, reconstructions, and protection of this historic building. Due to its bad technical condition, the Palace Complex in Gorzanow discussed herein required a comprehensive assessment, which will help to enable future preservation and reinforcement work.

The highest level of damage recorded during the survey resulted from mistakes made while using and repairing the building. Above all, the mistakes discovered resulted from lack of maintenance and faulty repairs, as the structure of the building had not been previously analysed. The result was a series of defects, caused by the impact of weather and climate conditions on structural elements of the building.

The highest level of damage was recorded in the central part of the palace – the east wing (Fig. 1), where incorrect repair work resulted in destroying parts of the roof. The original roof was covered with red shingles, and then roof tiles. The roof was later covered with ceramic tiles during repair work. The scope of repair work did not include reinforcing the wooden structure of the rafter framing, which demonstrated symptoms of biological corrosion that resulted from numerous areas of damp, which was almost certainly due to the effect of the bad technical condition of the roofing. The excessive loading on the rafter framing, due to much heavier ceramic tiles being places upon it, led to the collapse of that part of the roof. Load-bearing walls of the building were all that remained in the area of that construction disaster. The east wing that did not collapse was however leaky and each successive storey downstairs demonstrated numerous defects, which was a result of the impact of the precipitation of water. The following can be listed as the most frequently recorded types of defects: partial and complete failure of floors; significant development of biological corrosion on dampened materials; damage to stucco decorations on ceilings; damp in load-bearing walls, including loosening of plaster, and degraded structure and painting decoration on the crowning cornice. A large number of defects have also been discovered in the west section of the building – which contained residential rooms, as recently as 2011. The defects resulted from lack of roofing, both wooden elements and the masonry structure.

The roof in the west wing had suffered from long term degradation, resulting from the impact of weather conditions, i.e. snow load and rainfall.

The majority of the roof had collapsed under its own weight, resulting from a lack of maintenance and poor technical condition of the rafter framing. Severe damage was also been observed in the staircase in the west wing, which could possibly lead to a dangerous failure. Thanks to the good condition of the roofing (modern roofing systems), the north and south wings have been preserved in significantly better condition. The south wing features a number of modern structural solutions, while many elements of the wooden floors have been cut out (removed), due to poor technical condition. As for the brick vaults on the ground floor, they required securing. The polychrome Renaissance ceilings in the north wing have been well preserved. The defects recorded in the north wing primarily consist of large cracks on the external walls, looking from the north side. This structure contains buttresses, which were added some time after the palace itself had been built. This led to the conclusion that the cracks in that part of the building have been present for a long time. The reason for that could be an unstable foundation, which demonstrates significant damp and a high level of underground waters, on that side of the palace. The administration wing has also demonstrated numerous cracks.

Assessment of the technical condition was made on the basis of [3–5] survey which were conducted.

Fig. 1. View of the facade and roofing in the east wing, on the day of August, 2011 [2]

3. The scope of implemented repair work

In the fourth quarter of 2012, custody over the historic building was granted to Fundacja Pałac Gorzanów (The Gorzanow Palace Foundation), which started repair work, according to the construction disaster procedure, considering the collapsed roofs in the east and west wings.

The initial phase was basic securing work, which would prevent further destruction and devastation of the palace. The first step was a complete removal of the remaining rafter framing in the east and west wings – the entire area of the removed rafter framing was 1,300m^2. The roofing work carried out in the west wing was completed before the beginning of winter. The rafter framing was restored, and covered with full roof boarding and bitumen roofing paper. The structure of the rafter framing in the east wing has been modified from a structure based on collar beams and queen posts to a roof truss, which brought about a beneficial change in the static diagram and lightening of the wooden ceiling on the second storey, which had previously demonstrated significant deflections. The roofing on the cupola of a 55 m-high palace tower was also replaced. The scope of renovation included the dial-plate and workings of the clock, as well as all architectural details, up to the height of the roof ridge in the east wing.

Securing of the structure included carrying out of 500 m^3 of rebuilding (bricklaying), which was primarily related to the elements that demonstrated significant fracturing, cracking and defects. The work seldom involved reconstructing entire wall elements, but in some cases, load-bearing walls and ceilings were rebuilt. All repairs were carried out using ceramic brick, regardless of the different types of materials used to erect the original wall structures in the palace (Fig. 2). The dormer windows on the roof in the east wing have also been restored and filled in, during masonry work.

In addition, the securing of the building consisted of repairing and restoring the wooden beam-framed floors present in the palace (Fig. 3). All wooden elements were surveyed, based on which it was possible to select which elements could be left in place or reinforced, and the ones which had to be replaced. Some wooden floors have been replaced with floors based on pre-tensioned pre-stressed concrete, placed in the existing pockets, which enabled work to be completed more quickly.

Fig. 2. View of the administration wing and repairs which have been made using ceramic brick. Left side is a view on the day of February 2nd, 2013 to the right as at September 28th, 2013

Fig. 3. Wooden beam-framed floors restored in the north wing of the palace

4. Technical and organisational issues, regarding the carrying out of repair work

When carrying out the ambitious task of restoring the Palace Complex in Gorzanow to its full functionality and serviceability, a number of technical and organisational problems were encountered.

The condition of wooden beams and all other structural elements of the palace's tower cupola turned out to be far worse than initially thought (Fig. 4). Similarly, the rafter framing in the main building turned out to be in far worse condition than was expected after the initial assessment. Additionally, the weather at the end of 2012 and the beginning of 2013, as well as in the first months of 2013, did not permit the covering of the decked roof over the main wing with roofing paper, which extended the period in which the interior was soaking with water, and rendered it impossible to undertake work which was necessary in order to secure Baroque ceilings covered with stuccowork. This brought about many concerns, regarding the soaking walls which still contained precious decorations, including among others the ones in the *Sala Terrena*.

The scaffolding required to repair the palace's tower made it impossible to provide the proper protection of the joints between the roof and walls of the tower, during repair work (Fig. 4). Therefore, the mentioned joints were only temporarily protected against the weather, until the scaffolding was removed.

Fig. 4. View of the clock tower. On the left before renovation, to the right during the renovation

The north wall on the north wing at the main courtyard remains in very poor condition (it has probably been so for many years, considering the buttresses added on that side), which results from the instability of the slope in the park – which needs to be analysed with specialised equipment.

A large amount of soil which was deposited in the grange courtyard, during the post-war years clogged and obstructed the drainage and sewage system that has existed in the palace at least from its last repair in the years 1900–1906, and it also led to a significant damp in the walls and floors in the west wing. The east wing near the south courtyard (the so-called Classical wing) was damaged during roof repairs carried out in the 1990s, and it turned out to be extremely unstable. The funds collected for its repairing were only sufficient for the rebuilding and reinforcing of the west wall to preserve a badly damaged and collapsing vault inside the east wing, and the floor above it that constitutes the foundation for the floor of all rooms on that storey (formerly residential rooms), turned out to be a very demanding task, in the context of design and brick work. It was discovered that the walls adjoining the park (on the south side) were fractured, in that part of the wing. As a result, a drainage system was unearthed to remove water from that area – among others from under the building itself.

One of the significant organisational and logistical problems was the installation of floors based on pre-tensioned pre-stressed concrete, as it was impossible to move heavy construction equipment near the building. Consequently, the costs of installing girders were higher, than expected. However, it is worth mentioning that the overall costs of the repair work completed to this date has been consistent with the approved cost estimate of repair work. Naturally, there were some unexpected costs that emerged during repair work, for example regarding the repairing of the clock on the palace's tower. Nonetheless, the clock has been restored, as high costs would be incurred again in the future, resulting from the necessity to erect scaffolding.

The decisions concerning the sequence of carrying out each successive phase of repair work were predominantly the result of the amount of funds derived from the Ministry of Culture and National Heritage (500,000 PLN), the Marshal Office of Lower Silesia (60,000 PLN), and the National Fund of Environmental Protection and Water Management (384,000 PLN for the initial maintenance work in the park surrounding the palace). The guidelines specified through expert opinions and suggestions made by designers who cooperate with the Foundation have also been taken into account.

The philosophy behind the repair work was to ensure a significant level of "recovering" building materials, to re-use them in the future. However, only around 15.0% of stones and wooden structural beams have been recovered. Re-cut wooden elements will or have been re-used in the rooms of lesser spans (Fig. 5).

Fig. 5. New and old (recovered) structural elements used as part of the ceilings

The work schedule for 2014 is directly related to raising funds for carrying out this work. It will not be possible to determine, whether the plan can be completed and to what extent, without having any information about awarded grants. Still, the following scope of further repair work has been agreed:

- Carrying out of repair and protection work in the theatre wing, from January 2014 to July 2016;
- Continuation of repairs and protection work in all other wings, predominantly in the main building;
- Carrying out a detailed survey and securing the slope from the side of the park;
- Attempting to de-clog and restore the existing drainage system (drainages), or – should the first option be impossible – installing a new drainage system;
- Carrying out necessary conservation work in each successive wing of the palace.

5. Conculsions

Damage inventory and tests conducted make it possible to determine the current technical state of the Palace Complex in Gorzanow. Experiences from previously conducted renovations show that macroscopic assessment alone is not an appropriate for establishing the technical state of the construction, especially regarding wooden elements of the construction. The incorrect assessment of the technical state of the wooden elements of rafter framing ultimately lead to prolonged renovation, increased planned costs, and also create the possibility of further damage occurring.

The current problem for all ongoing construction is the impact of atmospheric conditions, which are especially dangerous in the case of historic buildings. In the Palace Complex in Gorzanow, this problem stems from the limited ability to isolate individual floors from precipitation and also from the high sensitivity of historic stucco and paintings to moisture.

It is not unusual that the order of implementing renovation projects in historical buildings is determined by acquired grants, which most frequently come from various sources. The order in which funding for specific tasks are obtained causes buildings to be renovated in an order which is not aligned with the recommended technological order. In the above mentioned conservation project, decision models were not implemented and the order of executing particular tasks was based on the system of funding. Most decisions regarding specific renovation issues stemmed from the need to allocate obtained funding.

Years of negligence, in terms of maintaining a building in an appropriate technical state, are very difficult to undo. However, protective renovation work conducted by the new owners of the Palace Complex in Gorzanow are encouraging and suggest that the palace and its entire surrounding will eventually be restored to its previous glory.

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TECHNICAL TRANSACTIONS | **CZASOPISMO TECHNICZNE**
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USAGE OF NEW SOIL IMPROVEMENT TECHNIQUES IN ROAD EMBANKMENT CONSTRUCTIONS

WYKORZYSTANIE NOWOCZESNYCH TECHNOLOGII WZMACNIANIA GRUNTU PRZY POSADOWIENIU NASYPU DROGOWEGO

A b s t r a c t

A gravel piles foundation technique as an alternative to the soil replacement method is presented in this paper. The authors describe both technologies and carry on the comparative analysis, regarding the economical and technical aspects of them. The work is based on a real life example from multi-storey car park construction project carried out in Tychy

Keywords: gravel piles, soil improvement

S t r e s z c z e n i e

W artykule omówiono technologię wykonywania pali żwirowych jako alternatywną dla wymiany gruntów metodę wzmocnienia podłoża gruntowego. Przedstawiono charakterystykę opisywanych technologii, a także wykonano analizę porównawczą, uwzględniając techniczne i ekonomiczne aspektu obu rozwiązań. W artykule wykorzystano dokumentację projektową parkingu wielopoziomowego wykonanego w ramach inwestycji przebudowy transportu publicznego w Tychach.

Słowa kluczowe: pale żwirowe, wzmacnianie gruntu

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1. Introduction

In recent years the construction of bigger and more sophisticated buildings has become a noticeable tendency in civil engineering. Projecting and constructing such objects is possible mainly due to the newer and more advanced building materials, as well as computer aided design systems used by designers and contractors. At the same time urban regeneration causes a lack of suitable terrain and thus poor ground conditions for such complex buildings. The characteristics of today's civil engineering issues described above, determines the progress of new foundation techniques. In view of the foundation for buildings issue, two types of foundation are considered: shallow foundation and deep foundation. First type is used usually used in favorable ground conditions. Spread footing, grillage, raft or inverted arch foundation can be specified as an examples of shallow foundation. The second group of solutions, is usually recommended for soils situated below the projected building where the ground is soft. Due to this, shallow foundations are not suitable for to transferring the loads from the building to the earth in safe way. The safe way of transferring loads to the earth is when the settlement of the ground below the building and does not cause structural damage to the building [1]. Pile or well foundations are performed in these unfavorable ground conditions, and both can be considered as an examples of deep foundations. In relation to dynamically developing foundation techniques on the market, it is possible to distinguish another group of methods where the soft soil strata can be strengthened.

In this paper methods of soil strengthening are listed and two of them are described. The gravel pile foundation technique is also presented as a foundation for a road embankment, based on a real life example from a multi-storey car park construction project carried out in Tychy. The solution is then compared with the soil replacement method. To conduct a comparison of the methods described, a time and economical analysis is performed.

2. Soil strengthening technologies

There are a wide variety of technologies which allow constructors to strengthen the soil structure below planned building. It would be impossible to describe all of the available methods of soil strengthening which have been undertaken by domestic authors in numerous literature in one paper [2–4]. Based on it, methods of soil strengthening can be categorized in fallowing manner:

– **Soil replacement**, where partial and total soil replacement can be specified, dry and wet (dredging) replacement methods are also available depending on the ground water table.
– **Soil strengthening without insertion of admixtures or other materials**, sorted into static and dynamic methods of soil compaction. Static methods are based on the application of preliminary loading of the subjected soil. Due to a consolidation effect induced by loading the parameters of soil improves. It is worth mentioning that classical methods of preliminary loading is very time absorbing. In order to speed up the consolidation vertical drains are used. This procedure speeds up the outflow of water from soils by cutting down the filtration path. Dynamic compaction, explosive compaction or vibroflotation are considered as dynamic soil strengthening methods.

– **Soil strengthening with insertion of admixtures or other materials**, where fallowing methods can be distinguish: surface stabilization methods, ground injections and a strengthened columns created in ground. There are several methods of forming columns in the ground, and at this point the vibro replacement method or the dynamic replacement method should be pointed out. Another popular technique is jet grouting where high pressure jet of fluid is used to break up and loosen the soil, and then to mix it with a self-hardening grout in order to form a stiff , durable column in the ground.

Another method used to strengthen the soil is a method where *geosynthetics are* designed. Finally soil parameters can also be improved by the implementation of *foundation piles,* in this group precast concrete impacted piles are popular and widely applied as a suitable technique.

In this work the authors precisely describe two soil strengthening methods: soil replacement by dredging and forming gravel columns in soft soils with the vibro replacement technique. Both technologies are analyzed in time and economical aspects, in a following part of this document.

2.1. Soil replacement by dredging

Soil replacement is a procedure where soft soils are partially or totally excavated, and the empty space is filled with a new soil material with the proper mechanical parameters. It allows for the creation of a foundation bed made of hard soil which can bear the load of the structure. Soil replacement can be carried out when the ground water surface is below the depth of excavation. If the ground water surface is above the planned depth of excavation, replacement can by performed by the dredge method.

The dredge is a method where excavation is made without pumping water out from the trench. After excavation is performed, trench is filled with soil by a bulldozers. In the end, the new stratum of strong soil is compacted.

2.2. Gravel columns

Gravel columns are formed in a ground by the vibro replacement technique which is a modification of the vibroflotation method. It is a popular technology with a wide spectrum of equipment and vehicles, used for creating columns. Because of that, the range of offered depth and diameter of columns is extensive. Furthermore, the ground condition in which columns can be implemented are very diversified.

Columns are performed by a specialized vibratory probes installed on a dedicated vehicle. According to the expected length of columns, an excavator or piling machine can be used as a dedicated vehicle. (when an excavator is used maximal depth is 7 meters and when vibrator is installed on piling machine, maximal depth is 20 meters).

The technology used for forming gravel columns can be divided into several characteristic stages. The first stage being a vibratory probe filled with gravel material is driven into the ground. Vibrator depth can be additionally aided by pressure from the specialized vehicle.

In the second stage the vibrator is pulled out while the aggregate is released from the tip of vibrator and fills the empty space. It is a stage when a gravel column is formed in the ground. Afterwards the vibrator repenetrates the soil, which results in pushing the gravel into the surrounding soil, and increasing the diameter and degree of compaction of column. This reciprocating movement of vibrator continuities along the depth of the shaped column. The final effect is an elastic column with a high shear strength. In addition during the process of forming columns, the soil near them is compacted which increases its mechanical parameters.

3. Application of gravel columns in foundations of road embankment using the example of a fire road around a multilevel car park in Tychy

3.1. Description of the investment and geotechnical conditions

The Fire road embankment foundation, which is described and analyzed in this article, is a part of "Redevelopment of Public Transport in Tychy – A Multilevel Car Park investment. Investment which is located beside the crossroad of the streets Adama Asnyka and Generała Andersa in Tychy. The Fire road is situated at the northern part of building, in the direct proximity of Potok Tyski river. On the grounds of geotechnical documentation made at the design stage, the existence of organic soil and a plastic silt strata was established in this area. These unfavorable ground conditions disqualify carrying out direct foundation of fire road embankment. Ground conditions were also confirmed in complementary tests carried out during the execution of the investment.

3.2. Presentation of analyzed design solutions

3.2.1. Preliminary design solution

Design documentation indicated the need for a complete exchanging of the ground by dredging, as a solution for a weak ground under road embankment. During the design verification stage carried out by the general contractor, it was shown that because of the complex ground conditions, high level of ground water surface and location of the road, it would be impossible to execute foundations according to design documentation without many additional works.

The inflow of ground water and surface water coming directly from the canal of Potok Tyski river was predicted in the case of excavation under the level of the water surface in the canal. Consequently the ground under the bottom of the canal could slide into the open excavation. To protect against this situation, the construction of an additional hermetical wall to a depth of 6 meters under the bottom of the excavation, would have to be prepared.

The next element not included in the design documentation, but necessary because of the terrain condition was a drainage system which would allow inflow from Potok Tyski river to be pumed out in the case of heavy rain. Further protection against flooding of investment where other works were in progress, would be to build a depression wells system with pumps and pressure pipes.

The difficulties described above convinced the General Contractor to look for alternative methods which would allow the road embankment to be built on the weak ground.

3.2.2. Alternative design solution

As an alternative solution which would provide the required load capacity for the base of the road embankment, would be to strengthen the ground using gravel columns. Considering the ground conditions, this technology seemed to be the optimal solution. The design project consisted preliminary of lowering the terrain and preparing a working platform necessary for the execution of gravel columns, which would be inserted into the ground to the depth approximately 0.5 meters under bottom level of the stratum of soft grounds. The level of the working platform was established, to avoid ground water problems and to prepare a guard bank against water from Potok Tyski river. Platform was executed from the embankment material and thanks to the proper organization of works, anticipating moving the piling machine over previously executed gravel columns, the platform was not damaged. Thanks to that it could be included as a part of the construction of the future embankment. Gravel columns of approximately 1 meter in diameter were carried out at spacings of 2,1 × 1,7 meter [6].

3.3. Time simulation of analysed solutions

In order to carry out a comparison analysis between the solution presented, time simulation in Microsoft Project Software was performed. The time simulations considered all necessary activities in both ground improvement methods. Labor consumption according to KNR (Catalogues Imputations of Matters) were considered as a standard model, which was also used during the economic study. This approach to the problem establishes reference elements for both cases.

Time simulation for ground replacement by dredging was carried out taking works included in design documentation and additional works, necessary for finalizing the task into consideration. Actions were sorted into four groups: The execution of a hermetical wall with a working platform for machines, sets of depression wells, excavation with transport and utilization of the material and filling the trench by dredging with transport of embankment material. The time line for this task is presented at the Fig. 1.

The analogical analysis was prepared for alternative solution in the form of ground improvement using gravel columns. In this case the following groups of tasks were specified: preparing working platform for piling machines with preliminary lowering the level of the terrain to the designed level, execution of canals to make surface drainage possible, forming gravel columns and making an embankment from the level of gravel columns to designed level. Fig. 2 presents the time line for described solution.

Based on the prepared models, the time necessary to complete all tasks connected with replacing the ground by dredging is 57 labor days, and for improvement the ground by gravel columns is 43 labor days. In both cases 12 hours labor day was considered.

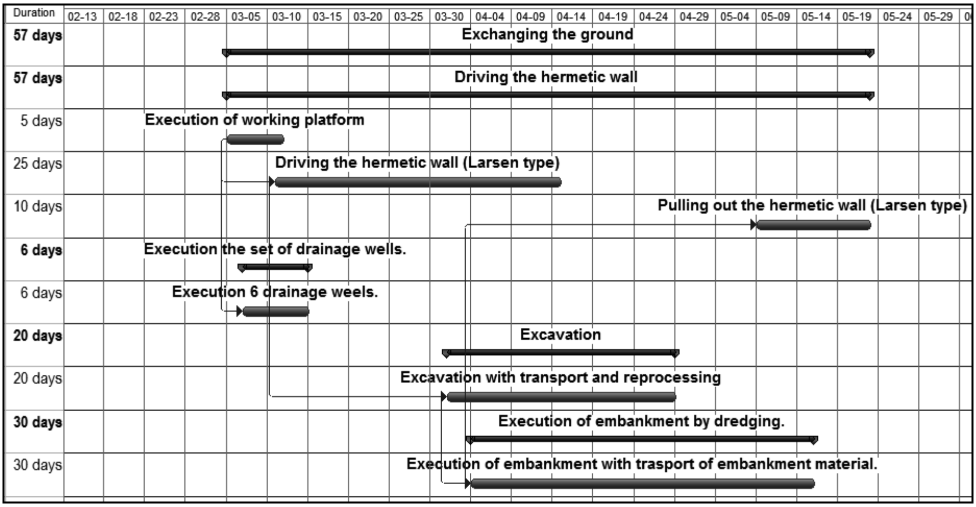

Fig. 1. Time line for exchanging the ground by dredging

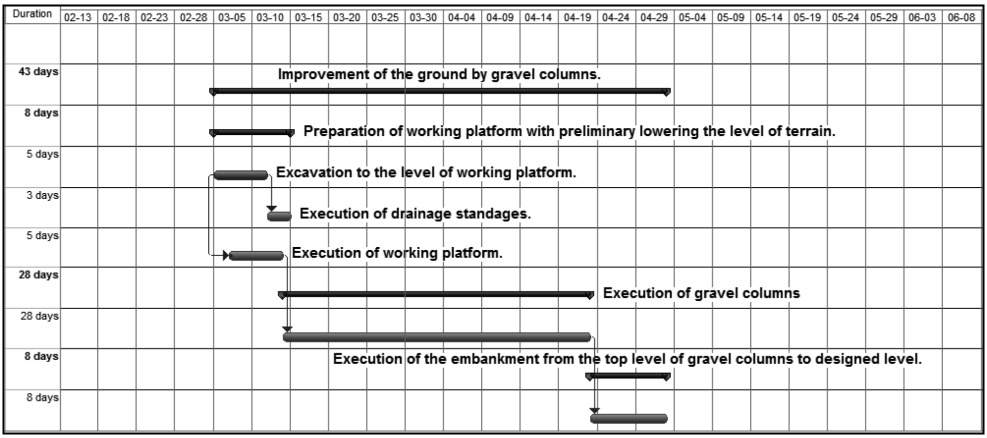

Fig. 2. Time line for improvement the ground by gravel columns

3.4. Cost analysis of described solutions.

For a comparison of economic aspects of the methods used to improve the ground under road the embankment, a cost estimation was carried out for both solutions. To show the level of the cost differences "Sekocenbud" bulletin for 4th quarter of 2013 was considered as a base for the cost estimation of works, including machine and material consumption. In both solutions a mid level of labor costs, renting the machines and buying the materials was considered. Calculation indexes of overheads were also considered as mid level for indirect costs and profit. This assumptions allows for a reliable comparison of solutions and demonstrate the percentage difference of costs. General cost estimations are shown in Table 1.

Table 1

General positions of cost estimation for analyzed solutions

Description	Value [PLN]
Ground replacement	
1. Driving the hermetic wall (Larsen type)	458537,09
2. Execution the set of drainage wells.	38066,40
3. Excavation with transport and utilization of soil material.	327724,90
4. Execution of road embankment.	1097475,44
Total value	**1921803,83**
Improvement of the ground by execution gravel columns.	
1. Preparation the working platform with preliminary lowering the level of terrain.	131489,99
2. Forming gravel columns.	193052,31
3. Building road embankment to designed level.	272164,98
Total value	**596707,29**

3.5. Conclusions

Considering the results of analysis presented in this article, the advantages of suggested alternative solution are easy to observe. Regarding the time consumption aspects and value of required work, soil strengthening by forming gravel columns is a more preferable technique. It is also worth noting that time analysis was carried out on the basis of premeasurements, which in the case of large volume ground works can be inaccurate, considering this fact using gravel columns is a safer solution regarding promptness.

Further analysis of results show the necessity of executing additional works in soil replacement method improves the cost of the project about 135% in comparison to the cost of dredging without extra works. Due to the works mentioned, operation completion time is almost double.

Another observation from result analysis is that even when additional works were not necessary, ground replacement method would still work out to be a more expensive solution.

4. Conclusions

Wide spectrum of available technologies for placing building on soft soils allows for the designing and execution of objects in almost any terrain conditions. Based on the investment project described in this article, it can be observed, that designers willingly choose traditional, checked solutions, however, when compared with new methods available on the market, these are proving not to be economically viable. Confirmation of this can be seen is the results of the time and cost analysis performed in this article.

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2-B/2014

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DESCRIPTION OF TECHNOLOGICAL AND ORGANISATIONAL PROBLEMS IN CONSTRUCTION WORKS USING THE EXAMPLE OF RESTORATION OF THE OUTER COURTYARD ON WAWEL HILL

PROBLEMY TECHNOLOGICZNO-ORGANIZACYJNE ROBÓT BUDOWLANYCH NA PRZYKŁADZIE REWALORYZACJI DZIEDZIŃCA ZEWNĘTRZNEGO NA WAWELU

A b s t r a c t

The paper discusses the process of restoration of the outer courtyard on Wawel Hill, which was part of a project co-funded by the European Union under the "Infrastructure and Environment" programme. The location and specificity of the restoration works generated many technological and organisational problems during their implementation (most of which could not have been predicted earlier), which in turn determined the different approaches and concepts available for solving them. The article is therefore a kind of case study, which demonstrates the specific implementation al problems associated with this project, as well as identifying the mistakes to be avoided, on one hand, as well as to point to concepts which are worth repeating..

Keywords: technology, construction plan, restoration of historical monuments

S t r e s z c z e n i e

W artykule omówiono proces rewaloryzacji dziedzińca zewnętrznego na Wawelu, który był częścią projektu współfinansowanego ze środków Unii Europejskiej w ramach programu „Infrastruktura i Środowisko". Miejsce oraz specyfika realizowanych prac rewaloryzacyjnych generowały na ich etapie wiele problemów technologiczno-organizacyjnych (w większości niedających się wcześniej przewidzieć), które z kolei determinowały różne podejścia i koncepcje ich rozwiązywania. Artykuł jest więc swoistym studium przypadku, które pozwoli nie tylko na poznanie specyfiki problemów realizacyjnych wspomnianego przedsięwzięcia, ale także na wskazanie z jednej strony błędów, których należy unikać, z drugiej zaś, wskazanie koncepcji wartych skopiowania.

Słowa kluczowe: technologia, organizacja robót budowlanych, rewaloryzacja zabytków

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1. Introduction

Construction works are a collection of construction processes, which include interconnected construction, technological and organisational operations and tasks, forming the basis for achieving the desired objective, which is to build a new structure, renovate an existing one, or carry out a demolition [1]. Properly selected factors of production (labour, materials and equipment) and high technological quality of building components are necessary for ensuring a smooth construction process. However, during the execution of the works there may be some unexpected situations, in the face of which it is necessary to change the previously scheduled technology and construction plan. Technological and organisational problems during construction works are therefore one of the key issues faced by the contractor at the implementation stage of the works.

While the deterministic nature of construction works leading to the creation of a new structure favours, at the time of their execution, the immutability of the previously planned technology and construction plan, in the case of a process associated with the restoration of a historic facility one must reckon with continuous change of this technology and construction plan. The unpredictability of the process of restoration is mainly due to the fact that we are dealing with historical material, which is not only building material that must be well examined in technical terms, but also is a carrier of certain cultural values. During the restoration process, situations can often occur, which were impossible to predict at the design stage, and are related, for example, with an archaeological discovery, which may lead to a change in the planning and execution of works, as it may be a consequence of the introduction of the so-called variation works or extra works. In any case, the decision for choosing the right technology and construction plan should be supported by a thorough, often multi-criteria, analysis, taking the restrictive conditions resulting from the circumstances and specificity of ongoing work into account [2, 3].

The purpose of this article is firstly to present the technological and organisational problems arising during the execution of works related to the renovation of the Outer Courtyard on Wawel Hill, along with access roads, and then to draw conclusions and offer guidance which should help in avoiding such problems in similar projects carried out in the future.

2. Objectives of restoration and its scope

Restoration of the outer courtyard on Wawel Hill along with access roads was part of the "Framework Work Plan on Wawel Hill for Years 2004–2010" carried out by the Royal Castle on Wawel Hill. This restoration was necessary due to the deteriorating state of the stone surfaces in the Outer Courtyard and access roads as well as the poor condition of underground infrastructure (water supply, sewerage, electrical, fire protection, and telecommunications networks). An additional objective of the restoration was to improve and reorganise circulation routes for tourist, ensuring access for people with disabilities. Improving the condition of historical monuments and enhancing the quality of services for domestic and foreign tourists as part of the popularisation of world cultural heritage made it possible to qualify this projects to Priority XI Operational Programme Infrastructure and Environment, Action 11.1 "Protection and Preservation of Cultural Heritage of Supra-Regional Importance".

Restoration of the outer courtyard and access roads (Fig. 1), included the following tasks:

1) replacement of underground infrastructure (water supply, sewerage, electrical, fire protection, and telecommunications networks),

2) comprehensive replacement of paved surfaces (about 10,000 m^2) with the reconstruction of outdoor stairs and the construction of a driveway and ramps for the disabled,
3) reconstruction of the stone toe wall along a pedestrian path and other landscaping elements,
4) construction of reinforcement and insulation of crownwork (old Austrian fortifications),
5) construction of irrigation systems for green areas.

All works were carried out under the strict archaeological supervision and the entire project was supervised by a conservation officer.

a)

b)

Fig. 1. View of a part of the outer courtyard along with access roads on Wawel Hill: a) during renovations, b) after renovations (source: Royal Castle on Wawel Hill archives)

3. Key factors generating technological and organisation problems during construction works

3.1. Uncertainties during the design stage

The basis for the proper restorative design of a historical monument requires in depth information about it (its past and existing state) and to analyse the conditions associated with the monument. However, in the case of historical monuments, the information gained by the designer during the survey is subject to a high degree of uncertainty, during the course of which design decisions can lead to varying results due to the occurrence of events, the likelihood of which are not known.

In the case of this project, uncertainty of information related to:

– Geotechnical parameters of the existing subsoil. The upper soil layers on Wawel Hill are in fact to a greater extent mixed with man-made fills (fills resulting from the rubble of demolished buildings, debris, ash and topsoil). This heterogeneity of the subsoil is difficult to verify, despite the implementation of test boring during the survey;
– The exact route and depth of existing underground infrastructure (routes of electrical, telecommunications, water supply, sewage and fire protection networks as well as other networks, which are not subject to repair, but which could come into conflict with the planned infrastructure.) Despite having access to the current site maps, inconsistencies of

the location of underground infrastructure, which over the decades has been rebuilt many times, could not have been ruled out;
- The number of and exact location of archaeological relics from the old buildings on the Wawel Hill. Currently, although this cannot be seen directly, Wawel Hill is the largest active archaeological dig in Poland, where objects of historical interest are being found with a varying frequency on an ongoing basis;
- The technical condition of underground structures such as the "Rabsztyn" archaeological reserve, the foundations of crownwork fortifications and others.

All of the uncertainties listed above mean that the technical solutions developed by the designer might not meet expectations at the implementation stage in the face of situations that were previously impossible to predict, which in turn will determine frequent design changes to achieve appropriate solutions, which will not always be possible to implement using the originally adopted technology and plan of work.

3.2. Limitations associated with the specificity and function of the structure and its surroundings

Basic limitations in this project include:
- A ban on the use of vibratory rollers for compaction of bedding layers of the renovated surface due to the protection of historic materials from adverse vibration;
- Limit on the use of heavy earth-moving equipment because of the
- potential archaeological finds;
- Constant archaeological supervision during the execution of earthworks;
- Limit on the use of heavy equipment for demolition due to the expected maximum recovery of stone materials from demolished pavement;
- Carrying out the works during constant tourist traffic (in an active facility) and interruption of the work for the visits of state and foreign delegations;
- Replacement of all underground infrastructure, ensuring continuity in the provision of utilities to open museum buildings (the need for bypasses);
- Restrictions on the movement of contractor's vehicles due to the safety of tourists and museum workers;
- Ensuring access for fire fighters and other services to the Wawel Hill buildings;
- Limited space for storage of building materials including those from demolition;
- Dependence of the work on changing weather conditions (three winter periods);
- Implementation of work in stages (division of the restoration into 12 stages).

4. Selected technological and organisational problems

4.1. Problems with the selection of shoring

Originally, the shoring technology for narrow excavations adopted by the contractor for the construction of a new sewerage system was based on the use of steel form work systems. Although this type of shoring installed in the excavation required the use of heavy equipment, this method allowed the contractor to maintain a high pace of work at relatively low cost of labour needed for its execution. However, during the course of the work it was found that this shoring technology could be used only in reopened excavations (i.e. on the route of the old sewerage network). In a situations when the route of the new sewerage network did not overlap with the existing one, the archaeological supervision forced the contractor to change the method of securing excavation walls using a (traditional) skeleton sheeting method (Fig. 2).

a)

b)

Fig. 2. Method of securing excavation walls: a) for reopened excavations b) for new excavations, with prior archaeological reconnaissance (source: Royal Castle on Wawel Hill archives)

This change in shoring technology allowed archaeologists access to the side walls of the excavation and provided the opportunity to carry out a complete analysis of the stratigraphy of archaeological layers which had not yet been investigated on the new route of excavations. Unfortunately, from the contractor's point, changing the method of shoring the excavations generated much higher labour costs, heavy and costly wood consumption and unfortunately prolonged the time required for this type of work.

4.2. Problems with the producibility of alternative solutions

Another example of the technological and organisational problems was associated with the strength of the subsoil during the construction of the pavement in the outer courtyard and on access roads. After constructing the roadbed and before laying geotextile and reinforcement geogrid and subgrade layers, an obligatory task was to check proper compaction had taken place at the bottom of the roadbed, and to compare these results with the design requirements. A static plate load tester was used to test the strength and in difficult to reach places, using a deflectometer. However, it turned out that the results differed significantly from the expected values. First, the contractor decided to try to use the current, planned method of reinforcing the weak subgrade using said geogrid. In order to minimise the expenditures on labour and equipment, it was decided to construct a 25 sq.m. trial plot, on which the contractor placed a layer of geotextile, geogrid and then two bedding layers made using aggregate with a grain size of 31.5 mm. However, the attempt to achieve the required strength at the level of the supporting bedding failed. Unfortunately, the replacement of the soil in order to improve its strength or its stabilisation using hydraulic binder as well as the attempt to improve soil gradation was not possible for archaeological reasons. As a consequence, it was decided to lay a geocell, i.e. a spatial system made of polyethylene tape in two layers, with a thickness of 20 cm each, with filling the space between "cells" using aggregate with a grain size of 31.5 (Fig. 3).

a)

b)

Fig. 3. Methods of strengthening weak soil: a) in the lower left corner the originally designed strengthening using geogrid can be seen, b) The said geocell (source: Royal Castle on Wawel Hill archives)

After the test on the trial plot, strength tests were carried out again, and this time results reached the designed value. Changing the method of strengthening the subgrade caused an increase in expenditures on labour and equipment as well as the execution time of one sq. m. of such reinforcement took much longer, not including the time needed to train workers for whom this solution was new. This spatial structure had to be laid manually. The method of compacting each layer of the geocell required the prior laying of a 5 cm layer of aggregate, whose task was to secure the top part of the geocell from mechanical damage due to rolling. After compacting and execution of verification tests, the protective layer had to be removed in order to implement another geocell layer. Thus, the level of producibility of the above solution meant that the implementation of such reinforcement was not easy in the existing production conditions.

4.3. Problems with the selection of demolition technology

The contractor's decision as to the selection of the right technology and construction plan was supported by a thorough analysis, taking the restrictive conditions resulting from the circumstances and specificity of ongoing work into account. It often happens that the originally adopted concept for a given operation proves to be suboptimal, generating an unnecessarily large workload. In this restoration project, one of the operations was to dismantle the wear course made of large stone slabs on the existing surface. In accordance with the guidelines of the conservation officer, the sandstone slabs after removal had to be evaluated for the possibility of their re-installation. This approach (the idea of maximum recovery of material) determined the need for their careful dismantling and moving onto hauling equipment, in order to take them to a place of possible further treatment. Attempting to manually disassemble slabs and their transfer to the designated place quickly proved to be inefficient due to heavy labour intensity, the consequence of which was the low efficiency of this operation. The large area of removed surface stone (over 4,500 sq. m.), the high cost of labour and time regime, demanded an immediate change of the technology and work plan through the use of special machines, whose pneumatic fittings allowed careful removal of stone slabs and efficient transfer onto hauling equipment. The investment in specialised equipment gave contractor tangible benefits in the form of high efficiency and much lower labour costs, and in the long term the equipment proved to be invaluable when laying new pavement (Fig. 4).

a) b)

Fig. 4. Methods of dismantling stone slabs: a) Manual b) Mechanical
(source: Royal Castle on Wawel Hill archives)

4.4. Problems with planning construction work

Restoration works had to be carried out with constant tourist traffic and for the entire duration of the renovation it was necessary to ensure access for fire fighters and other services to Wawel Hill buildings. To meet these demands, the entire project has been divided into 12 stages, the order of implementation of which was strictly specified in the baseline schedule. The division of the project into stages resulted in a lack of continuity in the performance of similar construction processes and uneven demand for means of production as well as problems in the planning of employment (Fig. 5).

5. Conclusions from the case study

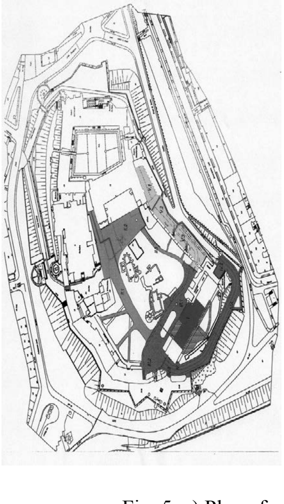
The analysis of the restoration case above allowed the authors to draw conclusions and propose (Table 1) guidelines, allowing contractors to avoid or reduce the risk of technological and organisational problems in similar future endeavours.

Table 1

Factors generating technological and organisational problems and proposals to avoid or reduce these problems (source: own work)

Factors generating technological and organisational problems in construction works	**Guidelines for contractors allowing to avoid or reduce technological and organisational problems in construction works**
Uncertainties arising from the weak reconnaissance of soil and water conditions, location of underground archaeological relics, routes and depth of existing underground infrastructure	As far as possible, the implementation of the so-called proactive actions (local test pits) to identify soil conditions, locate underground facilities and in consultation with the archaeological supervision, the believed location of archaeological relics
Possibility of extra works and varied works during construction	Providing skilled workers, and possibly universal equipment to efficiently adapt to changes of the producibility of building solutions
Archaeological and conservation restrictions related to the use of heavy equipment to carry out demolition, earthworks and surfacing	Providing small-sized equipment (e.g. compact excavators, small rollers (static), etc.) and taking into account (in the cost estimate and schedule) the possible need to perform certain works manually.
Execution of works in an active facility and the resulting limitations	Implementation and ongoing updating of detailed construction plans and traffic management plans and ensuring high safety culture

a)



b)

Fig. 5. a) Plan of renovation stages, b) Fire fighter exercises during construction works (source: Royal Castle on Wawel Hill archives)

6. Conclusions

Restoration of the outer courtyard on Wawel Hill along with access roads was a difficult undertaking. Complex works carried out over a large area, interfering with historical materials, implemented over a protracted period of time (30 months) generated technological and organisational problems. The guidelines proposed in the article (Table 1), may be helpful in avoiding or reducing the occurrence of such problems in similar future endeavours.

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KRZYSZTOF TRACZ*

METHODOLOGY OF LARGE PROJECT ACCOMPLISHMENT BASED ON NUCLEAR POWER PLANTS CONSTRUCTION

METODOLOGIA REALIZACJI DUŻYCH PROJEKTÓW NA PRZYKŁADZIE BUDOWY ELEKTROWNI JĄDROWYCH

A b s t r a c t

The paper looks at the systematic approach to management throughout the entire project life cycle. Some significant activities within particular phases of the overall process have been described in order to point out the fundamentals for a successful project. Planning assumptions, predicted risks and resources are always the basic parameters necessary for the optimal establishment of projec objectives. Further stages of projects need to be driven through those objectives while all contemporary constraints in the execution of the project have to be overcome by project team. The monitoring of progress and costs will always be critical for each contractor, however it becomes a real challenge when project requires the demanding quality and safety arrangements, as is the case when constructing nuclear power plants. The highest standards and procedures recommended for project management have been established in the UK and the USA. The main conclusions concerning the most important stages of project have been supported by examples of construction processes experienced by author in those countries.

Keywords: project lifecycle, project assumptions and risks, standards and procedures of project management

S t r e s z c z e n i e

Artykuł jest próbą systematycznego podejścia do procesu zarządzania pełnym cyklem życia przedsięwzięcia. W celu wskazania podstaw do pomyślnego zakończenia projektu opisano kilka działań znaczących dla poszczególnych etapów całego procesu inwestycyjnego. Założenia planistyczne, przewidywane ryzyka i zasoby określają zawsze podstawowe parametry niezbędne do ustanowienia celów projektu. Dalsze etapy przedsięwzięcia winny być prowadzone w odniesieniu do tych celów, a wszystkie występujące w tym czasie ograniczenia wykonawcze muszą być pokonane przez zespół zarządzający. Monitoring postępu robót i kosztów będzie zawsze dla wykonawcy robót czynnością krytyczną, lecz w przypadku budowy elektrowni jądrowych wypełnienie wymagających ustaleń kontraktowych dotyczących jakości i bezpieczeństwa staje się prawdziwym wyzwaniem. W artykule wskazano najważniejsze normy i procedury dotyczące zarządzania projektami, które rekomendowane są w Wielkiej Brytanii i USA. Główne wnioski dla ważnych etapów przedsięwzięcia podparte zostały przykładami zaczerpniętymi z procesów budowlanych, których autor artykułu doświadczył w tych krajach.

Słowa kluczowe: cykl życia projektu, założenia i ryzyka projektu, normy i procedury zarządzania projektem

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1. Project lifecycle

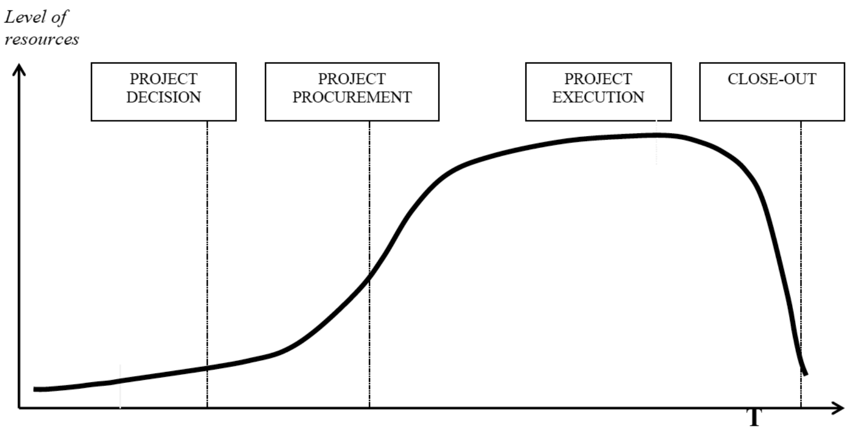
the performance of large projects has always been a challenge for all stakeholders throughout the life cycle of the project. Knowledge and experience in the execution of proper activities within the life cycle creates an obligatory base for effective results of all projects [1].

To date there has not been a standard guide for project life cycle published in Poland. Due to this, some flexibilities in the identification of necessary project activities are observed in general, particularly in the early stages of project. This also effects the efficiency of meeting project objectives.

British standard BS 6079–1:2010 provides guidance for managers in organizations which operate projects as well as for project sponsors. All project life cycles should include elements, which will be specifically identifiable for the project. Each project has its own phases, the decision points ("gates") without which next phase cannot be started and milestones – delimiting the further progress of works [2]. According to the above mentioned standard the names and numbers of project phases are determined in general by control needs of contractors involved as well as by the milestones of overall project cycle.

Generally project life cycles comprise two to six phases – seldom more than ten. There are 5 phases in average: initiation and planning of project, feasibility study, execution, maintenance and close-out.

Meanwhile the British *Chartered Institute of Building* (CIOB) recognizes eight stages of a construction project [3] (Fig. 1). Commissioning and taking-over stages were clearly distinguished from the whole process in order to pay more attention to engineering services and their important role in the technical approval of project scope.



I INCEPTION	II FEASIBILITY	III STRATEGY	IV PRE-CONSTRUCTION	V CONSTRUCTION	VI COMMISSIONING	VII TAKING-OVER	VIII CLOSE-OUT
Objectives	*Project brief*	*BIM & team*	*Designing & optimization*	*Project team interaction*	*Engineer services*	*Completion Occupation*	*Project audit*
Important resources	*Project execution plan*	*Control system*	*Contractual arrangements*	*Environmental management system*	*Testing & commission*	*Start-up*	*Close-out report*

Fig. 1. Stages in construction project according to CIOB (developed by author)

It should be pointed out that the construction process is a complete project just for the contractor but not necessarily most important for the employer. The distinct priorities of both parties result in different approaches to the common part of project. A building contractor is not usually involved in first three phases – inception, feasibility and the working-out of project strategy. This is probably the main reason project stakeholders underestimate these phases. However, the next "building" phases depend on them very much.

The overall scope of activities for building the **British nuclear power plant – Sizewell B** – had been broken down to seven stages of execution. The following milestones for these stages had significant meaning for overall life cycle of the project.
STAGE 1 – obtaining of public acceptance and optimization of power plant location,
STAGE 2 – confirmation of availability of technology licenses and designing,
STAGE 3 – contracting and execution of civil-mechanical-electrical design,
STAGE 4 – contractual procedures for civil – mechanical-electrical works,
STAGE 5 – performance of all construction works,
STAGE 6 – installation, testing and start-up of technology equipment – nuclear fuel load,
STAGE 7 – issue of safety and rating certificate.

2. Planning of larger projects

Due to a large scale of supplied materials and resources as well as due to the wide scope of branch works and technologies. the construction of a nuclear power plant has always been one of the most complex of projects. Therefore the investment process requires the implementation of management systems consistent with the effectiveness and quality of system requirements.

The construction of nuclear power plants has to be preceded by careful feasibility studies consisting a numerous sets of analysis. Impact on the environment and related activities are challenging when undertaking such a construction process. The environmental license as well as many technological, hydrological, geotechnical, seismic, geopolitical and legal parameters affect the optimal project location, therefore inspections leading to proper decision making usually accounts for 30% of the total time required for project completion.

British Nuclear Electric spent 5 years on initiation and design activities prior to a 7 year period of construction and the ultimate commissioning of Sizewell B nuclear power plant. The investment programme was derived from the project master programme which encompassed and iterated considerations covering design, licensing, manufacture, construction, testing and commissioning.

Iteration of all those processes underlies the basis for optimization of all major objectives. Satisfactory project objectives are always the most important condition for decision makers who have to consider external and internal assumptions, risks and the main resources necessary for project completion. To achieve the optimal balance between all of those parameters will always be challenging for project planners. Therefore the proper methodology has to be implemented in order to gain the project sustainability (Fig. 2).

Any default or mistake in this procedure will always result in various problems during the execution phase and projects are very often suspended or even canceled in such cases. The history of our Żarnowiec project shows how poor geopolitical assumptions could have led to wasting of time and money.

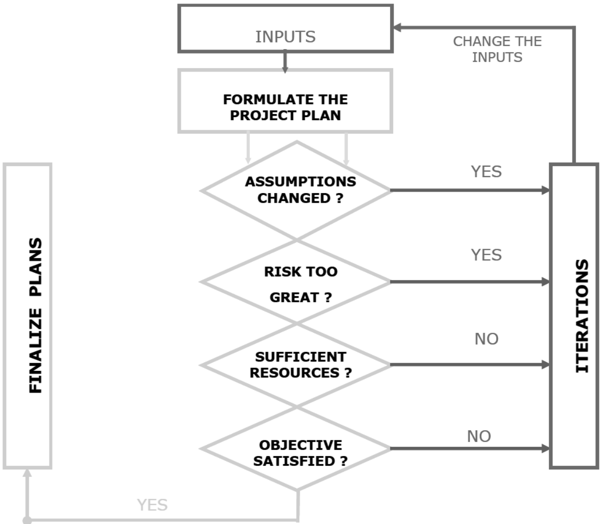


Fig. 2. Optimizing the project planning [4]

At the Sizewell B project many considerations were given environment issues. The Nature Reserve, the North Sea coastline and de-watering of the construction site without any draw down of the adjacent water level – were the main constraints to be overcome during the process of public inquiry and necessary licensing. Following the safety guidelines for the reactor structure the PWR (pressurized water reactor) system was approved, followed by the building of 1: 75 scale models. These models protected the work progress from many clashes and allowed for all of the key handover dates to be achieved and the whole project completed according to the master schedule.

Fig. 3. Execution of Reactor Bldg. in Sizewell B power plant (photo by K. Tracz)

Civil engineering design was managed under the cost reimbursable contract for most of the design period. When the remaining work could be more precisely defined, it was changed to a fixed price with progress related payments.

Rapid construction was pre-planned by plant being positioned in the lower floors of buildings in which the upper levels were still being constructed, thereby requiring the buildings to have temporary weather protection. To facilitate plant installation routes etc, access ways, construction openings, external ramps to ground level and concrete laydown areas were built into the design.

Meanwhile the current seven year-long construction of nuclear power plants in **Olkiluoto (Finland) and Flamanville (France)** had been planned for completion in year 2013/ 2014, however due to repeated time slides the real schedule date is expected to be around 2016.

To avoid common project management pitfalls the British CIOB paid particular attention to the following considerations [3]:

- Clear links between project and strategic priorities including agreed measures of success,
- Support, ownership and leadership,
- Effective stakeholder engagement,
- Effective project management and risk-management skills,
- Proper sequencing and scheduling of activities,
- Careful calculation of long-term value for money rather than overestimated initial price,
- Understanding of the supply chain,
- Integration between client, the project team and the supply chain.

The key to a successful project will always be well determined and analyzed Project Management Plan, often called a Project Execution Plan or Baseline Plan. It is a statement of policies and procedures defined by the project sponsor although it is usually developed by his project manager.

** According to British standard BS 6079-1:2010 the Project Management Plan shall be developed in order to set out the fundamental priorities and activities in respect to all management areas, of which a long list has been included in clause 7.1.4.2 of this standard.*

3. Project strategy

The main aims for the project decision-maker at the strategy stage include setting up the project organisation, establishing contributions required for the construction phase, delivery and commissioning issues through to identifying project targets, assessing and managing risks and working out a project plan. Therefore a typical strategy stage consists of the following elements : project brief, management structure, control system and procurement.

The procurement process should be considered to be most important as this formulates the basic inputs for other elements. It reflects the organisational and contractual arrangements which can be made to ensure that the interests of investor are safeguarded. The various procurement methods can be classified under the headings (Fig. 4):

- Traditional execution,
- Design-and-build,
- Build-Operate-Transfer (BOT),
- Construction management (Contract Engineer),
- Management contracting (Project Manager).

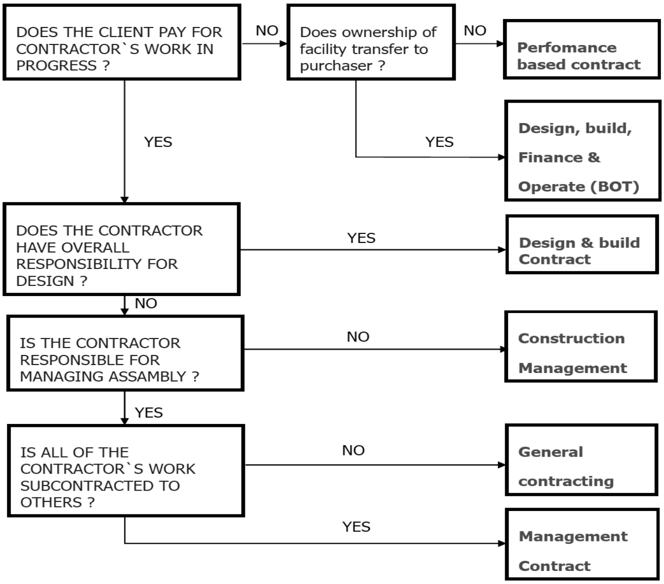


Fig. 4. Identifying procurement methods [6]

Careful considerations to be undertaken when preparing the scope of responsibilities and tender requirements for bidders. The consequences of not appropriate risks allocation as well as wrong formula of contract pricing are irreversible in most cases.

Public bids use lump sum pricing as an almost obligatory rule not taking into consideration all disadvantages related to such procedures. The mutual relation between scope changes, risks and incentives are usually underestimated by project sponsors and decision-makers (Fig. 5).

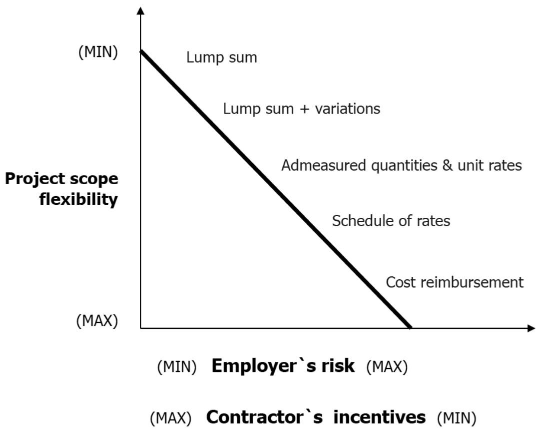


Fig. 5. Allocating risk through methods of payment [5]

Any default or mistake in this procedure will always result in various problems during the execution phase and projects are very often suspended or even canceled in such cases. The history of our Żarnowiec project shows how poor geopolitical assumptions could have led to wasting of time and money.

4. Construction and commissioning stage of project

In order to meet required objectives in such areas as planning requirements , entire life cycles constraints, value engineering, procurement methods, health and safety, environmental issues, and so on, standardization of project execution needs to be implemented. All of these conditions have a direct influence on the methodology of works to be performed on site. Ideally, construction will be undertaken in accordance with a detailed schedule. However, this ideal situation is only possible with perfectly-developed designs, which means for large-scale project … almost never. Most such projects, especially those using innovative technologies and designs, need proactive input from the project manager and all members of the project team. **The project manager has to steer the project to completion through continuous measurement of performance against time, quality and costs**. Therefore his broad skills are an obligatory condition for achieving success. Nowadays, various IT-based tools provide support for project management activities i.e. scheduling, earned value calculations, progress assessment etc. For the last few years the BIM (*Building Information Modelling*) methods have been dynamically developing and established models are considered to be a must for high-complexity projects.

Any major changes to defined fundamentals will usually affect time and financial aspects of project. However the negative influence of these changes could be limited and kept under control by using of proper procedure (Fig. 6).

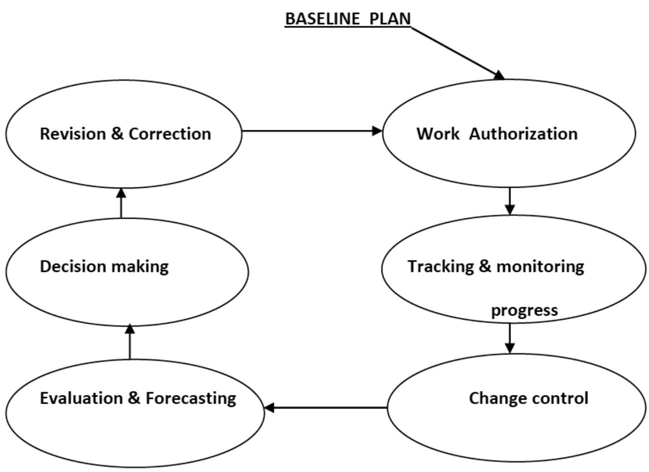


Fig. 6. The procedure of Project Plan control [5]

Testing and commissioning at Sizewell B was carried out under supervision of the independent quality assurance manager who reported directly to the project director. The quality department ensured the production of all the necessary QA procedures and documentation, including the quality system of suppliers and sub-contractors, and administered the site documentation centre. The QA department managed a team of independent inspectors who were closely involved in the inspection of all works on site, in additions to that carried out by site engineers. The regular review of non-conformism led to a significant reduction in rework and an improvement in overall costs.

Quality plans are the major references to the obligatory controls of all method statements, and the so called "hold points", do not allow for continuation of building activities without the inspectors release. International standards ISO 10005 and 10006 to be used for better organization of QA system on site [9, 10].

Continuous control through specified technical, managerial and financial monitoring of the project seem to be the "golden mean" for final success of every project (Fig. 7).

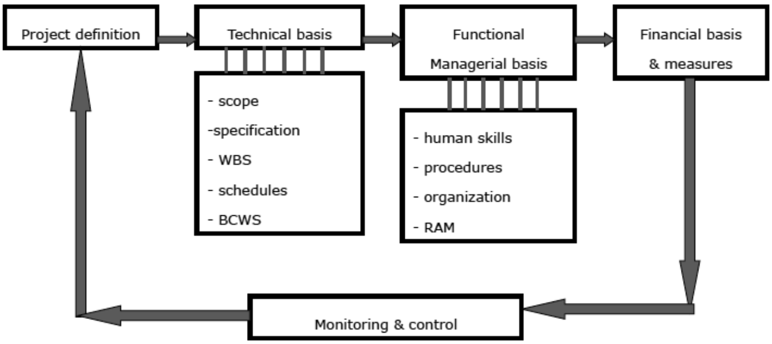


Fig. 7. Methodology of project execution according to Project Management Institute (PMI) [7]

5. Conclusions

there are many organizational, technical and methodological aspects described in this article with regards to large projects, such as power plant construction. Meeting project objectives as well as effective supervision should be based on proper risk allocation between the Employer and the Contractor, however all sponsors have to be aware that keeping full control of project life cycle leads to a greater risk acceptance. The introduced algorithms for project planning and procurement as well as methodology of their control might be a guide for key staff involved in projects in Poland, however some amendments resulted in polish legal acts yet to be implemented. One thing is for sure : the wider the scope of the contractors responsibility, the greater the risk of the employer losing control over the project. Therefore the proper supervision should be based rather on project management than on the contract engineering agreement. This conclusion is definitely to be considered by decision makers of the first nuclear power plant to be built in Poland.

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JAROSŁAW KONIOR*

INTENSITY OF DEFECTS IN RESIDENTIAL BUILDINGS AND THEIR TECHNICAL WEAR

INTENSYWNOŚĆ USZKODZEŃ OBIEKTÓW MIESZKALNYCH A ICH TECHNICZNE ZUŻYCIE

Abstract

Technical maintenance of existing buildings will be an important issue in the near future. The purpose of the research presented in this paper was to identify element deterioration in the course of maintaining residential apartments. In order to reach the research goal, the author analysed symptoms of the technical wear increase, i.e. performing the identification of mechanisms responsible the defect formation. The scope of this work required the creation of an original qualitative model for pinpointing defects and transferring this information into a quantitative one. Thus, it was possible to analyse the reason-effect phenomena 'defect – technical wear' relevant to the most important elements make an assessment of such an apartment block. The building in question is a block of apartment houses in Wrocław. The information gathered should prove indispensable for housing management and other such organisations involved with technical building services, as it can serve to influence the maintenance quality level of different types of existing buildings.

Keywords: building maintenance, reliability, defect, technical wear

Streszczenie

Racjonalna, systematyczna i rzetelnie przeprowadzana ocena stanu technicznego obiektów budowlanych stanowi podstawę do szeroko rozumianej organizacji ich technicznego utrzymania, a w szczególności do organizacji prowadzenia remontów i modernizacji o ustalonym rodzaju, wielkości i zakresie. Celem badań przedstawionych w artykule było rozpoznanie wpływu przebiegu procesów eksploatacji starych budynków mieszkalnych o konstrukcji tradycyjnej, na wielkość i intensywność zużycia ich elementów. Wyniki badań osiągnięto na drodze analizy objawów stopnia technicznego zużycia – poznania mechanizmu zjawiska powstawania uszkodzeń oraz identyfikacji wielkości i intensywności uszkodzeń elementów badanych budynków. Konsekwencją usystematyzowania najistotniejszych przyczyn wpływających na utratę właściwości użytkowych budynków mieszkalnych było utworzenie własnego modelu jakościowego i jego transformacja na model ilościowy.

Słowa kluczowe: utrzymanie budynków, niezawodność, uszkodzenie, zużycie techniczne

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1. Introduction. Mechanism of defect formation in building elements

1.1. A building element defect − definition

Defect formation is a phenomenon where an element or a building loses serviceability, [1, 4, 6, 8, 10, 12–16]. It occurs when building elements or buildings reach the limit state. Exceeding this limit state for the following service functions of individual residential building elements reduces their service potential. Upon reaching service limit state, the element loses its various service functions and its state is then described by the reliability theory as inefficient but fit for use. Such a state only lasts until all of the functions of the element have exceeded this limit state. Then the element is no longer fit for use. Service limit state is a conventional value, which depends on assumed criteria.

1.2. Defect formation under service limit states

Stimuli causing the use limit to be exceeded state that the following functions of of an element may fail suddenly (random defect) progressively, (defect due to ageing) or they may represent enforced strain relief (progressive ageing of an element and a sudden transition to an unfit state occur together). Progressive ageing processes are chiefly caused by defects of a deterministic character (i.e. that can be predicted during a certain period of time). Random defects occur suddenly (breakdowns, catastrophes) or they may be caused by the faster wear (process faults or defects). Faults (sporadic defects) represent typical defects caused by poor workmanship or low quality building materials, or they may be due to both these reasons simultaneously. Process (chronic) defects, on the other hand, represent defects resulting from erroneous design assumptions and faulty structural and/or material solutions. Poor workmanship and incorporation of low quality materials make the problem more pronounced.

Where a technical element suffers a sporadic or a chronic defect, its individual functions reach their limit state faster. The reason for this is a significant reduction in the material resistance to the action of external stimuli. Such defects cause sudden changes in physical parameters that control the performance of the element. During a breakdown, limit values of the safety function of the element structure are exceeded, whereas during a catastrophe the parameters go beyond required values. Progressive defects result from ageing processes. Ageing involves irreversible structural alteration of materials used to construct building elements. They are related to physico-chemical reactions taking place over time as a result of destructive stimuli that act in the macro and the micro scale.

The rate of material ageing depends on the following [1, 4, 10, 12–16]:
– resistance of the material to destructive stimuli,
– intensity of destructive stimuli.

Accumulation of effects of these impacts results in structural changes in the material. The effect of these external and internal destructive processes is a decreased resistance of the material to failures occurring at various stages of exploitation. Thus, a progressive increase in wear and a loss of service properties occurs, leading first to inefficiency and next to unfitness. Exceeding the limit state of individual service functions of an element still does not imply total physical destruction of the element has occurred. Entire physical destruction (and complete technical, social and economic wear) occurs, when major technical features, with regard to performance of service functions of the element do not meet parameters ensuring safe utilization.

2. Intensity of occurrence of defects in residential buildings as an element of reliability theory for technical objects

2.1. Reliability issue in the theory of exploitation

The issue of residential building reliability is always connected with the performance of exploitation tasks [3, 5, 7, 14, 15, 20]. The performance of such tasks in a residential building involves the proper fulfilment of certain functions by such a building, under given exploitation conditions and during a certain period of time. When this function is marked φ, building settlement conditions by χ, and the time of its settlement by t, then the task to be performed by the building can be described by an order of three [φ, χ, t]. By knowing a function to be performed by the building, one may determine such a set of requirements (ωφ) on a residential building, characterized by a number of main and auxiliary parameters pertaining to the technical-exploitation, economic and other aspects important in the process of exploitation and maintenance, that their fulfilment is the necessary and in a sufficient condition for adequate performance of the object functions (φ). A slightly simplified assumption, that the residential building in question represents a two-state object according to the theory of exploitation, i.e. it may be fit for its function (assuming the actual state characterized by fulfilment of requirements (ω φ), or unfit for performance of this function assuming physical state, by not meeting these requirements (ω φ). Then, the object tasks understood as an event (*Z*) (e.g. with regard to the provision of residential services) are presented as a the following ordered three: [ω φ, χ, *t*]. It was further assumed that both the requirements of a residential building, and conditions of its maintenance are known, i.e. that the pair [ω φ, χ] is set, as a result of which it was assumed that the reliability of residential buildings may be investigated with the function of time (*t*).

Residential building reliability was thus defined as follows: the reliability of a residential building is a property with the capacity to meet requirements (ω φ) within predetermined limits under given conditions of maintenance (χ) and the time of exploitation (*t*).

3. Impact of defects in residential building elements on their technical wear

3.1. A general scheme of a cause-effect model „defect − technical wear"

A general scheme of the cause-effect model „defect − technical wear" results from a synthesis of results of visual inspection of a selected sample of tenement houses. The scheme of the model in question at a most generalized level can be presented as follows:

SYMPTOMS
[CAUSES] → [observed ←→ measured] → [EFFECTS]

or in a more detailed manner:

FACTORS	SYMPTOMS	OUTCOME

⇩↓⇩↓⇩

what causes accelerated destruction of a residential building?	defects occurring	technical wear process taking place	what happens next to the residential building?

Fig. 1. A general scheme of the cause-effect model 'defect − technical wear of building elements'

To assess the technical condition of a randomly selected group of residential buildings and their elements, a group of experts acts at an intermediate stage of the proposed model − an analysis of observed symptoms is carried out. The causes (factors) are impossible to measure, but their impact may be taken into consideration during the assessment. As regards effects (outcome), one may distinguish between temporary effects (e.g. the loss of service values) and final effects(concerning decision on the future of a residential building). Further courses of action depend on the assumption of one of methods of multi-criteria decision making, e.g. as per [7]. Greater diligence and reliability of investigations of symptoms of residential building element deterioration carried out in the observed states results in more reliable premises for the further decision-making analysis.

3.2. A method to associate defects with the process of technical wear of residential building elements

3.2.1. A point biserial correlation coefficient as an indicator of various properties correlation

At the visual assessment stage, the extent of defects which could be found in tenement houses in a town centre included identification of two types of variables:

- Non-measurable – qualitative variables, i.e. individual defects present u_{ij},
- Measurable – quantitative variables, i.e. a degree of the technical wear of individual elements z_i.

The descriptive analysis and analysis of definitions of defects occurring in the apartment houses performed as a system analysis of 'conventional' sets does not allow for considering them as measurable variables at this stage of investigation. A major drawback of the method used by experts in the assessment of the technical condition of apartment houses was found in the fact that it did not express the magnitude (strength) of defects numerically. Even when the technical documentation was reconstructed with the best intentions and a review survey was performed, it was still not possible to distinguish between a measurable value of e.g. 'significant corrosion' of steel beams of stairs and 'strong corrosion' of an element, and between e.g. 'strong wear out' of electrical wiring systems from 'strong wear out' of another element. With this level of definition imprecision, elementary defect magnitude $u_{ij,}$ a decision was made to determine the occurrence (or absence) of a defect in the binary system $\{u_j\} = [0, 1]$, i.e. to make an assumption that the defect of a building element – identified at the basic stage – represents a dichotomous variable.

After the types of variables z_i and u_{ij} had been defined, an attempt was made at the numerical expression of relationship (should such relationships exist) between them, i.e. an attempt at measuring the influence of occurring defects of a building on the extent of the technical wear process of these buildings. In the calculation of the strength of this relationship, the method of determination of the point biserial correlation coefficient (generally marked as $r(Z)$) for the measurable property z_i and the dichotomous property u_{ij}, was used. This is one of a few cases in the statistics when properties of various types are being correlated [5, 7]. The coefficient of correlation value falls within an interval [–1, 1]. In the sets of defects U for each elementary defect $u_{ij} = u_i$ (when $j = 1, 2, \dots, m$) and the technical wear Z, the following was determined:

- u_i – dichotomous variable that takes on values 0 (u_{i0}) or 1 ($u_i 1$); $i = 1, 2, \dots, n$;
- u_0 – number of observations of the variable u_i marked as 0;
- u_1 – number of observations of the variable u_i marked as 1;

apparently $u = u_0 + u_1$ (if by u, one shall understand the number of all observations u_i), and:

- z_i – measurable variable; values of this variable were divided into two groups distinguished on this basis: whether u_j takes values 0 or 1; $i = 1,2, \dots, n$;
- z_{i0} – value of the property z_i for these units 'i', for which the property u_{i0} occurs;
- z_{i1} – value of the property z_i for these units 'i', for which them property u_{i1} occurs.

Next, arithmetic averages were calculated in the both groups:

$$\overline{z_0} = \frac{1}{u_0} \sum_{i=1}^{u_0} z_{i0} \tag{3.2.1}$$

$$\overline{z_1} = \frac{1}{u_1} \sum_{i=1}^{u_1} z_{i1} \tag{3.2.2}$$

the standard deviation (determined for the correlation $r(Z)$ with a relationship defined in a different way):

$$d(Z) = \sqrt{\frac{u \sum_{i=1}^{u} z_i^2 - (\sum_{i=1}^{u} z_i)^2}{u(u-1)}} \tag{3.2.3}$$

and as a result, on the basis of (3.2.1 – 3), the point biserial correlation coefficient $r(Z)$:

$$r(Z) = \frac{\overline{z_1} - \overline{z_0}}{d(Z)} \sqrt{\frac{u_1 u_0}{u(u-1)}} \tag{3.2.4}$$

The method of associating of defects in elements of buildings with their technical wear shown above, makes it possible to determine the direction and the strength of this relationship was used in the investigation of the influence of the defects present on the process of the technical wear in the following stages of apartment houses inspection:

- the observed state, where the correlation coefficient was calculated in all five classes of apartment houses technical wear $r(Z) = r(Ze)$ and separately in each of three medium states of maintenance of apartment houses $r(Ze)$II, $r(Ze)$III, $r(Ze)$IV;
- the theoretical state, where the correlation coefficient was determined for technical wear calculated in the classes I –V with the use of time formulas and a bi variant assumption of the expected life T of building elements:
- quoted in literature [13] $T^* = T$(Thierry), $r(Z) = r(Zt^*)$;
- maximum $T^{**} = t_{max}$, $r(Z) = r(Zt^{**})$.

Values of point biserial correlation coefficients calculated in this way for the 10 selected building elements were presented in the description of their defects, characterised by theoretical and observed states. A numerical representation of the reason-effect relationship 'defect – technical wear' contained in them was supplemented with calculated differences of the average value 'DE' of those values of the technical wear Ze, Zt^* and Zt^{**}, for which $u_I = 0$ and $u_i = 1$. In the tables comprising of results from the author's own investigations of theoretical and observed conventional states, values of probabilities $p(u)$II, $p(u)$III, $p(u)$IV of occurrence of defects of the elements analysed in the whole sample are also presented.

3.2.2. Testing of significance of the point biserial correlation coefficient in a sample with a recognized value

Analysis of reason–effects relationships 'defect – technical wear' presented collectively for 10 selected elements of buildings, points to a considerable range of strength of these relationships within the same type of elementary defect $u_1 - u_{30}$ (Tab. 3.2). In order to compare the scope of the change in correlation to the defects and of the technical wear with the direction of change of the intervals of partial probabilities $p(u)$II, $p(u)$III, $p(u)$IV they were presented in one table (Tab. 3.2), where values of associations of the defects that present the strongest correlation (i.e. $r(Z) > 0.5$) with the technical wear were highlighted.

Due to such a great dispersion in the relationship between the measurable variable z_i and the dichotomous variable u_i the author decided to test the significance of this correlation in a sample, carrying out from 95 to 102 measurements for 10 selected elements of apartment houses. The test of significance of the correlation coefficient $r(Z)$ was performed, as in the case of the *Pearson and the Spearman* tests [2, 9] with the use of the Student's t statistics, defined in the following manner:

$$t = r(Z)\sqrt{\frac{u-2}{1-[r(Z)]^2}} \tag{3.2.5}$$

with the number of degrees of freedom $d_f = u - 2$. As a result, a precise probability $p(r)$ was calculated through the obtaining of such a value of the t statistics, as the with the one obtained on the basis of the representative sample, with an assumption that the null hypothesis H_0 ($r(Z) = 0$) was against the alternative hypothesis H_1 ($r(Z) \neq 0$) and with the determination of the two-sided criterion region. The probability $p(r)$ corresponds to the significance level observed. In the case of the linking of various properties, it should not be an error to accept a significance level of 10%. In order, however, to decisively single out those types of defect that have the strongest influence on the level of building element technical wear, an assumption was made that if $p(r) < 0.05$ then if the correlation tested is indeed significant, whereas if $0.05 \leq p(r) < 0.10$ then one may regard this as a tendency towards the relationship sought after. Table 3.2. lists values of point biserial coefficients of association $r(Z)$. Highlighted are those that show the strongest correlation (at the significance level of 5%) and those that show a tendency towards the relationship between the defects occurring and the extent of elements technical wear of the apartment houses.

3.2.3. Extrapolation of results for the sample onto a homogenous population of tenement houses

All the samples of the 10 selected elements used in the tenement houses in question represent large statistical samples ($u > 30$), and comprise of between 15.8% and 17.0% of the parent population of 600 buildings. Approximation of the normal distribution $N(0, 1)$ was used to extrapolate results for the sample defined in this manner on the entire population and to determine confidence intervals for the point biserial correlation coefficient in the parent population. It was assumed that each of the confidence intervals will cover the true value of r (being an estimator within the population of a correlation coefficient calculated from the sample), with probability $1 - p(r) = 0.95$. For the value of the cumulative distribution function $\Phi(x) = 0.95$ in a normal distribution with the average of 0 and the standard deviation of 1, the value of statistics in this case amounted to $x = 1.96$. The correlation coefficient $g(Z)$ in the parent population is determined by the lower and the upper limit of the confidence interval in the following dependence [9]:

$$r(Z)_d < g(Z) < r(Z)_g \tag{3.2.6}$$

that is:

$$r(Z) - x\frac{1-[r(Z)]^2}{\sqrt{u}} < g(Z) < r(Z) + x\frac{1-[r(Z)]^2}{\sqrt{u}} \tag{3.2.7}$$

It was also assumed that the square of estimator $r(Z)$ corresponds to such a percentage of the parent population, for which the data obtained can be considered at a confidence level of 95%. Confidence intervals were determined, between which coefficients of correlation between the defect of elements of buildings analysed and their technical wear in the parent population and its size were determined, while distinguishing those whose $g(Z)$ is of at least moderate strength ($r(Z)_d > 0.45$).

4. Conclusions

4.1. Conclusions from the research of intensity of formation of defects in residential buildings on their reliability

The principle conclusion concerning the mechanism of defect occurrence in residential buildings stands for a period of the building exploitation during which the time of proper function until defect is characterized by exponential distribution (this is in fact the second and also the longest period of exploitation), an average period of failure-free work is constant at any time. Thus, in theory, after a certain period of failure-free service, residential buildings perform their functions as do the new ones. A rational time for repair occurs after the second exploitation period is over, and before the period of sudden increase in the wear of the residential building.

The theoretical approach to the issue of intensity of formation of defects in residential buildings with regard to the change in their reliability enables the following conclusions to be drawn:

- the generally applied, standard definitions of reliability of buildings facilitate the research and interpretation of the course of exploitation processes of residential buildings,
- various reliability characteristics in which the function of defect intensity (that provides for the creation of other reliability indicators) is of crucial importance and should be used for the purpose of the comprehensive evaluation of changes in the reliability level of residential buildings,
- utilization of reliability characteristics of a residential building for the purpose of repair decision making enables development of a rational repair strategy, e.g. by allowing for the determination of repair intervals on the basis of defect intensity distributions,
- expression of the average failure-free service of the building (τ_0) by means of the reliability function $R(t)$, that defines probability with which the time of the proper exploitation of the building is longer than has been has been practically applied in the process of exploitation for the residential building and its components.

4.2. Conclusions from investigations of the influence of defects on the level of technical wear of residential buildings

The results of the reason-effect relationship 'defect – technical wear' research in a representative sample of town centre apartment houses erected with the use of traditional methods make it possible to present the following conclusions:

- the direction of the relationship is (as expected) right-hand (positive) for all 10 building elements tested but the strength of correlation between the defects detected and the technical wear shows a considerable span (between 0.00 and 0.84),
- as a rule, the strongest influence on the technical wear of elements in the tenement houses investigated is exerted by defects related to water penetration and moisture ingress (group II) – 0.54 on an average, while the correlation is significant in all cases,
- the technical condition of each of the elements investigated also show an influence of defects typical to their own constructional type with regard to the structure and material, for example:
  - no less important defects of wooden parts of the elements (floor beams, treads of stairs, roof truss, window joinery) attacked by pests (group IV) – $r(Z) \cong 0.42$,
  - mechanical defects of the structure and surface quality (group I), while the significance only really concerns those elements in which the defects mentioned here may be the reason for the increased influence of the subsequent defects (cumulative), e.g. of main walls of the basement, the above-ground structure and of the interior and exterior plasters (but not of the foundations or solid floor over the basement);
- defects observed in the loss of the initial shape of wooden elements (group III) may be regarded as insignificant; an exception is the skewing of window joinery – correlation

0.42 – in the case of which, this defect brings about a considerable loss of the usable value of the window joinery,

- The extrapolation of results of the reason-effect relationship 'defect – technical wear' research in a representative sample of town centre apartment houses onto a parent population of 600 tenement houses leads to the following general conclusions:
  - in each of the elements (except for the inter-storey wooden floors) there occurs at least one (up to three) correlation coefficient $g(Z)$, determined on the parent population, and characterized by a moderate strength of the relationship in question ($0.45 = r(Z)d < g(Z) < r(Z)g = 0.70$) or quite strong − ($0.60 = r(Z)d < g(Z) < r(Z)g = 0.80$); very strong correlation ($g(Z) > r(Z)d = 0{,}80$) was not observed,
  - as a rule, a correlation of at least moderate strength is always revealed by the defects caused by water penetration and moisture ingress (group II); only in cases of inner plasters and facades the mechanical defects of the structure and the surface of the elements can be treated as moderate and quite strong,
  - for the assumed confidence level of 95%, dependences of moderate strength can be refereed to as 34–48% of a parent population and the quite strong correlation – to 49–71%.

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REPAIR PROCESS IN THE PITHEAD BUILDING AND ITS INFRASTRUCTURE AS AN EXAMPLE OF REPAIR WORKS IN INDUSTRIAL FACILITIES

PROCESY REMONTOWE W BUDYNKU NADSZYBIA ORAZ JEGO INFRASTRUKTURY JAKO PRZYKŁAD REALIZACJI ROBÓT REMONTOWYCH W OBIEKTACH PRZEMYSŁOWYCH

A b s t r a c t

This article presents the technological issues of carrying out repair works on a pithead building in Upper Silesia. The problems diagnosed by the authors and connected with the uncontrolled settling of the pithead building and neighbouring facilities caused the need for developing a repair works schedule that enabled its continuous operation. The paper also presents a method for the implementation of the recommended works and their impact on the technical condition of this object, its functionality and operation.

Keywords: repairs, diagnostics, jet grouting

S t r e s z c z e n i e

W artykule przedstawiono problematykę technologii wykonania oraz przeprowadzenia prac naprawczych budynku nadszybia w jednej z kopalń węgla kamiennego znajdującej się na terenie Górnego Śląska. Zdiagnozowane przez autorów pracy problemy związane z niekontrolowanym osiadaniem budynku nadszybia oraz obiektów sąsiadujących pozwoliły opracować program prac naprawczych umożliwiających ich dalszą eksploatację. W pracy przedstawiono także sposób realizacji zaleconych prac oraz ich wpływ na stan techniczny omawianego obiektu oraz jego funkcjonalność i użytkowanie.

Słowa kluczowe: prace naprawcze, diagnostyka, jet grouting

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1. Introduction

Buildings located within mining plants are interesting examples of industrial facilities. Their technical condition affects not only the safety of their users but, above all, the ability to conduct, often continuously, the technological processes of excavation. Even small disruptions in the operation of a pithead facility may result in a total stoppage in mining activities. It is therefore important to maintain such facilities in good condition, which often requires continuous monitoring of their behaviour under the influence of static and dynamic loads acting upon them. In case of any irregularities which could lead such facilities to the state of structural failure, immediate repair actions leading to their proper operation should be carried out. Such a situation was recorded at a coal mine located in Upper Silesia. In this mine, as a result of uncontrolled displacement of the ventilation duct which also served as a foundation for two poles of the pithead building, there may have been additional tension in the structural elements of the building. Research carried out by the authors, which included the description and analysis of the current state of the structure, along with photographic documentation, static and strength control calculations that took the forced uneven settling of the foundations into account, as well as an analysis of the results, conclusions and recommendations for further operation of the building, which allowed for developing a repair schedule.

2. General characteristics of the pithead building

The building in question is located in a former swampy area, which has been evened out using made ground. The pithead building was also designed to house a ventilation exhaust. The pithead included two depression chambers for trolleys transporting auxiliary material, an airlock for the staff and a leisure facility. With the transformation of the shaft into a downcast shaft, the conditions were changed for the building, thus changing its depression load. The total area of the pithead building is 350.10 m^2, and the total volume is 3.127.00 m^3.

According to geotechnical documentation, the area around the pithead building is filled with man made ground consisting of slag, brick, stone, clay and sand, down to the depth of 2.00 m. Below is a layer of sand dust and clay with a thickness of 1.00 to 2.00 m. Below that, there are low- and medium-cohesion soils consisting of dusts and dusty plastic clay. The last layer includes ground water of low aggressiveness.

The main load-bearing structure of the building is made of a single-nave, single-storey steel frames hinge-joined with the foundation every 6.0 m. The walls are made of prefabricated reinforced concrete slabs welded to the structural columns using suitable fasteners. The roof structure is made of typical prefabricated A-4/K ceiling slabs supported by the rafters of the framework. A general view of the support structure of the pithead building and the building itself are shown in Figure 1.

Columns in gable walls in axis 3 are suspended on struts due to the lack of space on the foundation (shaft head building). In axis D, two frame columns in axes 3 and 4 are supported by a ventilation duct section separated by movement joints and constructed to transfer the load from the frames. The plinth in the form of a clinker brick wall on cement mortar is laid on prefabricated ground beams supported by foundations. The foundations were made as a group for the individual columns interconnected with safety beams that secure the

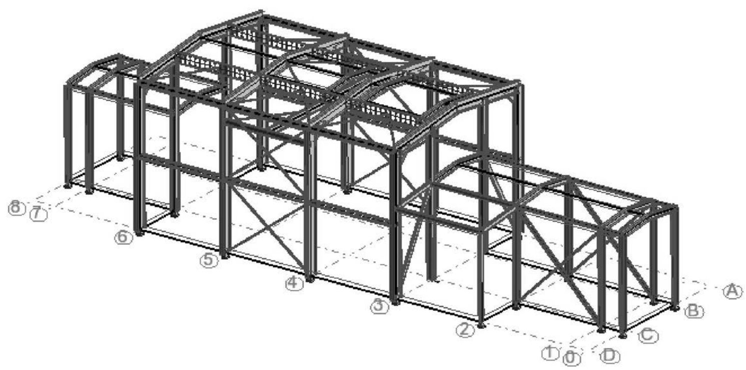

Fig. 1. Supporting structure of the pithead building

foundations against excessive horizontal displacement. The foundations are placed 1.5 m below ground level, with only the previously mentioned pillars of the framework in the axis D. Axes 3 and 4 transfer the loads to the ground via the stair structure of the ventilation duct on which they are placed. The solution adopted for the foundation of the pithead building allows for independent operation of individual groups of foundations.

3. Evaluation of the technical condition of the pithead building

In July 2011, site visits were conducted, which included the direct area around the shaft, the ventilation duct and the pithead building. The observations and measurements of the geometric dimensions of the facility included an assessment of the technical condition of the building. Based on the site inspection, the following conclusions were made:

- damaged floor in the area of load-bearing columns support on the ventilation shaft,
- damaged hinged joints of the framework column in axes D and 3 with the foundation, displaced J-bolt in relation to the ventilation shaft,
- damaged curtain wall in axes D and 3 – vertical slots,
- damaged infill in the curtain wall in axes D and 3,
- damaged external reinforced concrete wall panels – debonding and slight vertical and horizontal displacement,
- loosening of wall elements from the building’s plinths,
- damaged wall corner of a pithead building addition,
- slight displacement with rotating ventilation shaft, noticeable in expansion joints,
- lack of progress in expansion joints loosening based on installed infills,
- vertical displacement ventilation shaft in relation to the shaft head.

It was concluded that this damage may have been caused by uncontrolled displacement and rotation of the individual parts of the ventilation shaft. This would have been caused by the method of setting the pithead building, which included supporting the framework columns in axes 3 and 4 on the section of the ventilation shaft surrounded by movement joints. The in fills allowed for constant monitoring of the possible acceleration of the loosening of observed slits and damages. It was also concluded that the factors which caused the displacement of individual elements of the ventilation shaft have stabilised, which was proven by the lack of damage on the seals and the results of systematic geodesic measurements.

During site inspections, no damage was found in the joints of main or auxiliary elements. The steel components were properly protected against corrosion and the measurements did not show any dimensional deviations from the designed values.

4. Evaluation of the current carrying capacity and serviceability of the pithead building

Assessment of the current technical state allowed for static and strength calculations to be carried out for the pithead building. Calculations were performed in a calculation program using Finite Element Method and included:

- building a computational model based on the available archival documentation and the inventory of current state,
- the determination of internal forces in structural elements,
- the determination of deformations and displacements,
- inspection to check the load capacity of selected, representative steel components.

Based on the inspection and available technical documentation, a computational model for the pithead building was constructed. The model takes the geometric characteristics of the individual components and their interconnections into account. A summary of loads in this analysis was performed in accordance with current standards and regulations [1–6]. In the case of wind and snow loads, changes resulting from the amendment of the provisions of code were also taken into account. Due to the change in the function of the ventilation shaft from exhaust to downcast, the air depression load was omitted in the loads. The model also takes the uneven settling of the foundation of the pithead building into account. As a result of the uneven settling of the supports of the pithead structure, the forces and deflections are distributed differently in the main elements of the structure. The values of internal forces and torques in steel columns and beams are thus altered. The calculations do not take the stiffness of both the wall and roof elements into account, which, significantly increase the structure's rigidity due to the permanent nature of their joints.

Table 1 shows the values of maximum cross-forces, as well as maximum tension values in the structural elements. Figure 2 shows an example of a graph of maximum torque M_y.

Analysing the values of maximum tension obtained, we can conclude that they do not cause maximum effort in the steel profiles. Stress with approx. values of 150.0 MPa should be safely transferred by the structural components used.

Table 2 shows maximum displacement values for the structural nodes of the pithead building in the limit state of usability.

Table 1

The maximum values of internal forces and stresses occurring in the structural elements of the pithead building

	F_X [kN]	F_Y [kN]	F_Z [kN]	M_X [kNm]	M_Y [kNm]	M_Z [kNm]	σ_{max} [MPa]	σ_{min} [MPa]
MAX	843.91	16.25	123.62	0.17	654.40	27.99	152.23	145.08
Rod	73	31	73	65	73	124	52	123
Node	61	12	62	54	62	88	35	73
MIN	–210.55	–31.11	–272.36	–0.22	–654.40	–3.29	–146.17	–146.17
Rod	77	46	75	64	75	65	132	132
Node	66	31	62	54	62	58	63	63

Table 2

The maximum values of displacements of structural nodes in the pithead building

	U_X [cm]	U_Y [cm]	U_Z [cm]	R_X [rad]	R_Y [rad]	R_Z [rad]
MAX	0.0	4.4	0.0	0.005	0.012	0.005
Node	4	10	4	55	54	41
MIN	–4.0	–1.6	–3.6	–0.008	–0.007	–0.001
Node	62	56	85	12	87	55

A maximum displacement value of 4.4 cm was obtained in node no. 10 of the structure, which is located in axes 6 and D in the joint between the column and the beam. Due to the fact that the stiffness of both the wall and roof elements were not taken into account, and their permanent joint with the structure significantly increases the overall stiffness, the real registered displacements should be lower. It should be further emphasised, that the forced settling of the foundations related to the settling of a section of the ventilation shaft is a decisive factor causing the deformations. Calculated deformations, taking the additional stiffening of certain panel elements of walls and roof into account, should be safely transferred by the structure in question.

Based on these calculations, it can be concluded that no limit state in those elements is exceeded. However, further settling of the ventilation shaft, as well as the foundations in axes C and D in the southern part of the pithead building, should be limited. Further settlement growth will significantly reduce the load capacity of the main structural elements and can lead to exceeding the limit states of load capacity and serviceability of the building. Due to the positive experience of the mine with foundation reinforcement in this area using micro-piles, the previously used solutions should be adapted to protect the foundations of the

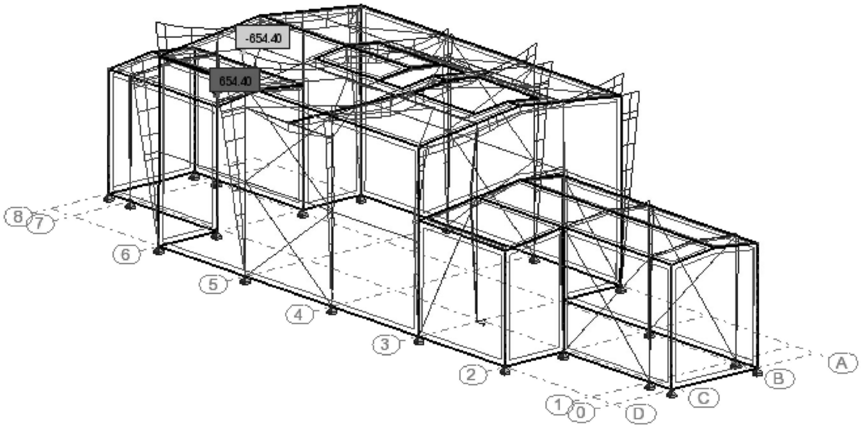

Fig. 2. Graph of maximum torque M_y of the pithead building structure

pithead building. The use of appropriate technology to reinforce the foundations would also allow for the rectification of the facility.

5. Repair works on the pithead building

The diagnosed issues connected with the uncontrolled settling of the pithead building and neighbouring facilities necessitated the development of a repair project which allowed for its continuous operation. To this end, "Georem" Sp. z o.o. engineering company developed a project [7], which included strengthening of the existing foundations of the pithead building, the construction of heaters, reinforcing the floors near technological channels in the buildings, as well as the ground adjacent to the ventilation shaft. All repair works were carried out in autumn of 2012 and included the following execute:

- site preparation where the works would be conducted,
- 5 geotechnical holes on the outside of the buildings,
- 3 geotechnical holes inside the ventilation duct,
- injection columns under the existing foundations,
- injection columns in the immediate vicinity of technology channels,
- vertical barrier in the immediate vicinity of the existing duct,
- low pressure injection under the duct's base plate,
- organising the work area.

The proposed high-pressure jet injection was the technology used to strengthen the foundations of the ground, a tried and tested method used for thirty years. It was moved from to Japan to Europe in the 1970 's. This technology is characterized by three specific features which are useful in applications relating to strengthening the foundations of buildings. Jet grouting technology provides the possibility of drilling small diameter foundations (about 100–150 mm). From a relatively small diameter drilling pile, the creation of a substantial diameter pile can be achieved. These features together with using drilling equipment with a small footprint allow for the effective implementation of the consolidation work in almost all technical conditions, even from a basement not exceeding 1.5 meters in depth. It should be emphasized that in the analyzed case, jet grouting technology enabled the implementation of all repair processes without any major disturbances in the use of the building headroom, which was a main assumption for the selection of technologies for strengthening the ground and foundations.

In order to strengthen the ground below the existing spot footing and continuous footing, columns with a diameter of 60 cm and the length of 7.5 to 10.0 m were designed. Prior to forming the columns, re bores were carried out on the existing foundations.

In order to strengthen the subsoil in the immediate vicinity of the technological channels, columns with a diameter of 60 cm and the length of 4.0 m were designed.

To prevent the excessive settling of the duct, a vertical iris was designed using columns with a diameter of 80 cm and the length of 8.0 to 10.0 m. Additionally, in order to strengthen the subsoil directly beneath the base plate of the duct, holes were made for low-pressure injection (classic injection).

The jet grouting technology used filled any voids, caverns and loose material that could appear in the ground, e.g. as a result of ground water.

5.1. Column injection molding technology

Column injection involves drilling holes in the soil and the formation of column shafts using the kinetic energy of a stream flowing out of a nozzle, which hews and fills the ground with the injected grout using the rotation and the concurrent upwards and downwards motion of the drilling tool. Cement grout made of cement is most widely used as the injected medium.

In this case, injection columns with a diameter of 60 cm and 80 cm were designed at proper working levels. Working level adjustment maintained the level of column bases while the designed geometry below the foundation outline were also maintained.

For works safety reasons, control cross cuts were made prior to drilling in order to locate existing underground installations. In the event of a conflict between existing installations with the designed columns, the colliding installations should be moved or the geometry of injection works should be changed.

The works preceding the drilling and injection included:

- control cross cuts in order to locate the underground development,
- performing optional demolitions in order to access the drilling locations and preparing the working level for column construction (drilling level),
- starting the works on 60 cm and 80 cm columns.

The columns were constructed in the following order:

- drilling holes through floors, walls, building foundations,
- drilling holes in the ground to the proposed depth,
- constructing the columns by jet grouting.

To perform the injection work according to the technology described, specialist equipment was used. The basic elements of this equipment are:

- drilling with equipment (head injection, injection line, monitor injection, jets),
- high rotary mixer,
- slow rotary mixer,
- high-pressure injection pump,

- manometer,
- scales to measure the density of the cement paste.

The transport of materials and equipment was made by commonly available transport sources which were adopted to carry the certain goods.

During the realization of repair works the control studies were conducted. These studies included:

- materials used for the column injection,
- inject work and their compliance with the design documentation,
- strength of the cement-soil compressive,
- diameter made of columns.

5.2. Technology of low pressure injection

In order to reinforce the ground directly below the foundations of the ventilation duct, low-pressure (classic) injection was used for the purpose of eliminating any possible loosening, washouts or caverns. For this purpose, holes with a diameter of 50 mm were drilled vertically through the base plate every 0.75 × 2.3 m with a displacement every second row.

The injection procedure should be conducted using packers. Grout injection was carried out sequentially in the adjacent holes until a significant leakage in the next hole was noticed or the injection pressure increased to a pre set value. Drilled holes were treated as safety valves in the event of a pressure increase above the permissible value. The maximum injection pressure measured directly in the hole was P_{max} = 0.2 MPa. In the case of high absorbency of the soil, characterised by a lack of grout flow in the adjacent holes, injection should be discontinued and restarted after 24 hours.

Injections were considered completed when pressure increased above the preset value P_{max} = 0.2 MPa with minimal absorbency of the grout.

5.3. Executive recommendations and notes

Before drilling and injection could start, existing soil development networks had to be precisely located. In the event of a collision with planned works, the placement of columns had to be adjusted. Regulatory distances from injections to foreign devices had to be maintained.

All devices and installations, or their parts, that were located in the vicinity of the works had to be turned off, stripped of all hazardous factors and successfully secured against accidental launch and appropriately marked.

Prior to the commencement of works related to grout injection, 8 geotechnical holes had to be drilled to prove the assumptions concerning the soil. In the case of any deviations in relation to the assumptions, appropriate design and work decisions had to be made and agreed upon with the designers.

The works associated with drilling down to the predetermined depth had to be carried out using cement grout. Due to the occurrence of cohesive soil in the substrate, wet scrubber drilling was inadvisable.

During the injection works in the direct vicinity of existing channels, their technical condition had to be checked first to secure them against filling with technological dump. If necessary, piping had to be laid in the section in direct contact with the technological channel.

After the designed works have been completed, as-built documentation had to be compiled.

6. Evaluation of the effectiveness of made the repair process

Mine engineers have been making geodesic measurements near the pithead building for many years. Measuring points were placed both on the building and on its floors. The geodesic monitoring allowed for determining both the past displacement of measurement points and the effectiveness of the repair process carried out. The measurements obtained show that the largest vertical displacements prior to repairs occurred in the direct vicinity of the resting place of the column in axes D and 3 on the ventilation duct. Total displacement at this point was 3.1 cm. Slightly smaller displacements of 1.6–1.9 cm were recorded at points located in the vicinity of the wall in axes B and 1–2, as well as C and 1–2, and at a point in the vicinity of the foundation shaft tower brace. Other displacement measuring points did not exceed 1.0 cm, and extra points installed after finding displacement of the ventilation duct showed no significant changes.

Fig. 3 is an exemplary diagram of vertical displacements recorded at measuring point No. 78, located on the wall in the immediate vicinity of the resting place of the column on the ventilation duct. It should be noted that significant displacements of 2.4 cm at this point were recorded directly before the repair works commenced (18.09.2012). As a result of the repair process, the displacements have stabilised and are currently not hazardous to the pithead building. It should be emphasised that similar relationships have been recorded at other measuring points.

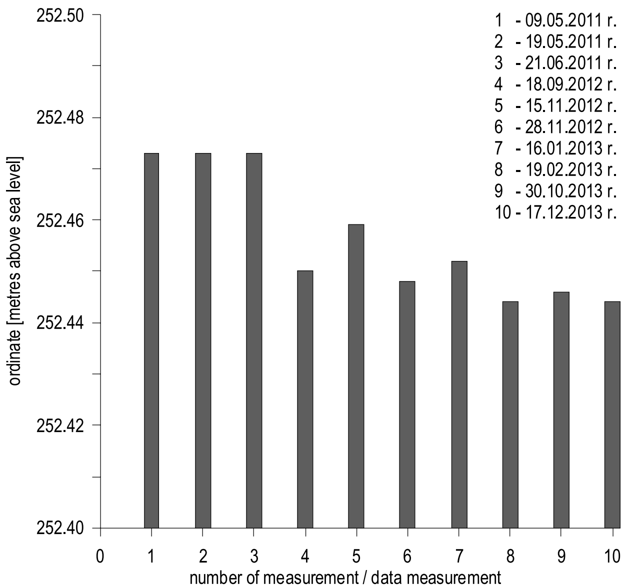

Fig. 3. Vertical displacements of measuring point no. 78

7. Conclusions

Repair works to industrial facilities, not unlike other facilities, is a complex issue. When designing and performing such tasks, one should take a number of factors that may hinder their performance into account. The correct assessment of current technical conditions, taking real condition of the structure and the factors causing the loads into account seems very important. The example of repair works using jet injection technology presented in this article points to the desirability of this type of solution, particularly in situations where work has to be carried out quickly. This technology guarantees safety of the structure as well as minor interference to the environment object. It should also be noted that all repair works were carried out without causing any major disruptions to the operation of the mine. Previous positive experiences related to the use of jet grouting technology for repair works on industrial facilities show great potential.

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2-B/2014

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ROLE OF MONITORING A CONSTRUCTION PROJECT WITH THE APPLICATION OF THE GRAPHIC VISUALISATION METHOD

ROLA MONITORINGU W PROCESIE REALIZACJI PRZEDSIĘWZIĘCIA BUDOWLANEGO PRZY WYKORZYSTANIU METODY GRAFICZNEJ WIZUALIZACJI

S u m m a r y

The main goal of monitoring construction projects is to identify any negative deviations from the approved plan. Therefore, the possibility of the permanently monitoring the progress of construction work scope is an extremely important issue. The authors' main goal is to present a method of graphical visualization which can be used for tracking progress in relation to the time, progress as a supplement of the cyclograms.

Keywords: graphic method of visualization, monitoring of construction work, cyclograms

A b s t r a c t

Rolą monitoringu w procesie realizacji przedsięwzięcia jest wychwycenie wszelkich negatywnych odchyleń od przyjętego planu. Stąd tez możliwość permanentnej kontroli postępu wykonania zakresu rzeczowego jest niezwykle istotna. Celem autorów było przedstawienie metody graficznej wizualizacji postępu procesów w odniesieniu do postępu czasu jako uzupełnienie cyklogramów.

Słowa kluczowe: graficzna metoda wizualizacji, monitoring robót budowlanych, cyklogramy

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1. Introduction

The effective monitoring, as "an integral part of the daily management of any construction project", should be based on the systematic observation of the construction project progress in the planning phase as well as in the realization phase. The computer programs available for the management of the linear construction projects, currently used in the domestic market, base on the graphic form of a cyclogram, using interpretive possibilities contained in the process of the graphic visualization. Traditional forms of project management support systems present their results in the form of bar charts or network diagrams. However, the current forms of graphical visualization used for the planning and progress of construction work during a project realization (i.e. the Line of Balance – LOB), as well as the above mentioned computer programs for the management of construction projects, do not contain time lines for tracking progress on time-space diagrams with charts showing realized tasks. Therefore, the main goal of the authors was to present the idea of a graphical presentation for tracking progress in relation to the time, using line charts on a common space formed by:

- increasing construction realization progress, presented by the cyclogram of tasks;
- downward sloping line of the time progress during the construction project realization, as an objective benchmark for the estimation of progress of tasks realization in relation to the amount of remaining time.

The method presented complements the cyclograms of tasks, through the direct, visual reference of the progress of construction work to the line of time progress, which is in the charts space. Moreover, the method complements the elaboration of the knowledge base, organization, risk estimation and controlling and construction project realization, widely described in the following references [1–12].

2. Monitoring in process of construction project realization

One of the most important roles of monitoring is spotting the initial (very often difficult to monitor/observe) messages regarding potentially negative consequences for the success of a construction project. Therefore, the possibility to transform the collected data/information and the ability of full use of the results (with application of the programs supporting the project management processes) is very significant. Data resulting from the monitoring of tasks, processes and construction projects should be used in the subsequent procedures. From the analysis of different monitoring methods applied, the user can draw the following conclusions:

– The graphical method of presentation, on the one chart, the level of advancement and progress of the processes, which are "difficult to measure" (such as: the intensity of management processes and time progress) is applicable after inserting the common units for the all meters of processes.
– The controlling plays a leading role in the initiating and realization processes.
– In the remaining phases, the controlling influences simultaneous to the planning and realization processes as well as to the realization and closure processes.
– The mid-term evaluation progress results should be known and implemented at the beginning of the second half of the process realization.

– The concept of a graphical progress presentation (running in parallel or as independent tasks) processes, together with the visualization of the real declining time resource (intended for their realization), enables the possibility of comparing – in a natural way – the state of progress of the monitoring processes to the real amount of time required in order to complete the construction project.

3. Idea of method of graphical presentation of construction work progress

This paper aims to demonstrate the graphical presentation of interactions between the processes (which often goes in parallel way at the different levels of activity and which are at the phase of growth or closing). Then, the current state of their progress, at any time, can be directly compared on the chart, in relation to the time period remaining for completion of the construction project.

The authors have made the following assumptions:

1. The controlling (called: *Controlling Processes*), as a group of control actions, proceeds "from the earliest initiating actions";
2. The ordinates, at the selected points of the activity graph, are the measure of the working time expenditure, needed to reach the required level of activity in a particular phase of the process;
3. The period of time (called: *Time*) means the time period of construction project realization measured in weeks, months, years;
4. The time progress during the realization phase has a linear interdependence, such as the ordinates decreasing from "1" to "0" are placed on the axle marked at the point of completion of a project.

According to assumptions, the authors draw vertical sections corresponding to the ordinate axis (called: *Level of Activity*), characteristic for the levels of advancement in the particular phase of the analyzed processes. It can be noted (see Fig. 1), that the particular curves illustrate the separate processes running in parallel as well as the total amount of time required to achieve the correct level of project advancement in the particular phase.

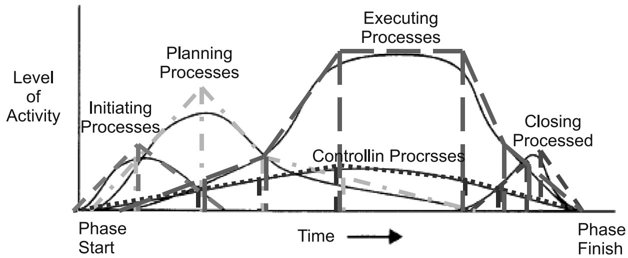

Fig. 1. The intensity dependence of project management processes from the phase of its realization

Assuming that the area under the curves proportionally reflect expenditure or activities which have to be completed at particular phases of the construction project, one can calculate the value of working time expenditures required in each process. For the analysis, the authors have made the following assumptions:

1. The advancement degree of the analyzed process in the particular phase of the construction project realization – the ordinate of the obtained level in the examined period (e.g. the number of working hours “w-h”) will be marked on the vertical axis of the working time expenditure on a scale from “0” (at the start of the construction project) to the value obtained, which is the actual amount of working time expenditure required to achieve the current level in the examined period;
2. The progress of time is a constant value (in a given period of the construction project duration), which represents a straight line connecting two zero points of time in the project duration – the starting point and the point on the vertical axis inserted at the point of project completion, indicating use of the whole period of time.

As a result of such procedure, the authors have obtained a graphic picture of monitored activity progress of particular processes and the total chart of the amount of working time expenditure necessary to ensure the realization of the whole construction project with respect to parameters of time progress for the duration of realization of the analyzed processes.

The comparison of many different variables course, such as elements of construction works scope or the financial works scope in relation to the real passage of time, have the same units and location on the surface defined by the vertical axis located at the start of the construction project. In the vertical axis the increasing values of the working time expenditures progress and the other vertical axis located at the end of the construction project are marked, where (in the decreasing scheme) the ordinates of the time progress during the construction project realization are determined.

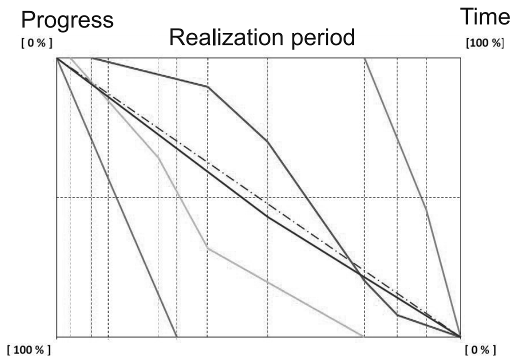

Fig. 2. The monitoring processes progress in relation to the time progress

In Fig. 2, the graphical presentation of individual process realization progress is presented. The innovation of such a graphical presentation method, showing the relationship course between different elements of the processes (taking place during a construction project realization) and its duration is a result of the corresponding graphical approach on the chart elements: the rate of processes with the rate of time passage. This practical property has a few methods, which are applied for the current monitoring of the selected elements progress in the project management process, both in the planning phase and in the realization phase.

4. Basic features of graphical presentation of construction work progress

The concept presented (in the form of line graphs) for the construction progress work scope against the time progress elapsed in a non-custom layout of ordinate axis (for the assumed parameters of progress) and is distinguished by the following basic features:

- at the start of the construction project, progress for the entire construction project (which require carrying out during the scope of processes creating the construction project) is 0%, and the planned amount of time assumed by the project realization period is 100%;
- after the start of realization, the level of tasks advancement (within the individual processes) is growing and transforming directly as project elements come closer to realization, to 100 % of the construction work scope,
- for the duration of project realization, the passage of time is shown by the straight line, connecting the start point (which is the beginning for the construction work scope) and which is also the beginning of the realization period, with the end point of the graph, meaning the realization of the planned phases and the use of 100% of time for the project realization;
- the progress, shown in a graphical way, which takes place in relation to the visualization of time progress, enables a rapid and clear estimation of the current state at the realization phase of the construction project as well as enabling a diagnosis of potential risks and the identification of measures to be used (e.g. the additional resources);
- the line of time progress at any point is the reference level for the specified (also in [%]) completion of the monitored elements in periods specific to the selected project or established for the purpose of monitoring;
- preparation (at the planning phase) of the graphs of realization for each element creating the construction project on the background of the graph of time progress during the planned or required realization time, enable the user to make adjustments in the length of the realization period or in the rate of achieving the required level of activity (called: *Level of Activity*). The increasing rate of construction work is presented in the chart as the increasing angle of the progress chart segment moves towards the timeline;
- the course of the project element progress line located above the line of time progress shows the realization of this process with delays in relation to the current progress of the time project.

5. Conclusions

In summary, the elaborated version of the schedule in the form of line graphs, due to the properties of the method of graphical presentation of the construction work progress against the contract time progress discussed above, meets the criteria to be the tool which allows the user to control the entire task and monitor progress of the contract. At the same time, it could helpful for the participants in the investment process (in decision-making process) in emergency situations which may affect the completion of the contract in time. The proposed method of the graphical presentation of the construction work expenditure progress in relation to the time progress (as the basic tool for monitoring) has no equivalent in any previously used methods of supporting the project management.

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2-B/2014

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MONITORING OF BUILDINGS IN SELECTED STAGES OF SERVICE LIFE (SL) – CASE STUDIES

MONITORING OBIEKTÓW BUDOWLANYCH W WYBRANYCH ETAPACH CYKLU ŻYCIA (SL)

A b s t r a c t

The paper discusses the functions and objectives of systems, used for a building's monitoring process, through the subsequent stages of a building's service life. The authors present the result of research regarding the monitoring of two buildings undergoing refurbishment: an industrial hall and a multi-storey general use building. Refurbishment of the industrial building included upgrading an existing production line, associated with an increased technological load. In the general-use building the foundations were strengthened in connection with the construction of a new multi-storey building in the immediate vicinity. The process of reinforcing footings, or – pilings – was monitored, as well as the preservation of an existing building, during the course of the construction of the new building.

Keywords: structural monitoring, service life of a building, safety of use

S t r e s z c z e n i e

W artykule omówiono funkcje oraz cele monitoringu, wyodrębniono i scharakteryzowano elementy systemów monitorujących. Podano zakres procesu monitorowania w kolejnych fazach cyklu życia obiektu budowlanego. Autorzy przedstawili wyniki badań dotyczące monitoringu dwóch obiektów poddanych modernizacji: hali przemysłowej oraz budynku wielokondygnacyjnego użyteczności publicznej. Modernizacja budynku przemysłowego polegała na unowocześnieniu istniejącej linii produkcyjnej, co związane jest ze zwiększeniem obciążenia technologicznego. W obiekcie użyteczności publicznej wzmacniano fundamenty w związku z posadowieniem w bezpośrednim sąsiedztwie nowego budynku wielokondygnacyjnego. Monitorowano proces wzmacniania ław fundamentów (palowania) oraz zachowanie się konstrukcji istniejącego obiektu w trakcie realizacji nowo wznoszonego budynku.

Słowa kluczowe: monitoring konstrukcji, cykl życia obiektu, bezpieczeństwo użytkowania

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1. Introduction

Monitoring (*monitor*, Latin: *admonitory*) denotes the regular qualitative and quantitative measurement of indicators (parameters) of an examined phenomenon as well as information about deviations from normal conditions. Monitoring has two functions: observation and warning. The intensive development of electronics, computer science and the Internet have led to monitoring systems being used in almost all areas of human activity. Construction is an area of the economy, in which monitoring also plays an increasingly important role. The objective of these studies is primarily to enhance safety at every stage of the service life (SL) of a building [8] and the sustainability of buildings. Information collected during the monitoring process can be helpful when choosing the appropriate action in the event of any adverse impact from certain factors (phenomena) on the building process or the safety status of the building. The monitoring system , regardless of the area of its application, consists of the following elements [1, 2, 5, 6, 13]:

– The monitored construction or its parts: foundations, floor slabs, walls, roof trusses, etc.;
– Sensors – for measurement of studied values: deformations, displacements, strain, pressure, temperature, etc. These are devices that convert the measured parameters into a different scale, usually electricity, which can be easily transmitted. The type of measuring apparatus and its location should be determined individually and adapted to monitoring conditions. New capacities create more accurate apparatuses and GPS (Global Positioning System) methods. This is particularly true of surveying techniques;
– Data acquisition system – frequency measurements, resolution of measured signals, application filters, etc.;
– Transfer and data input in the computer centre with all the necessary software to enable the processing of signals, analysis of the results obtained and a final evaluation of technical conditions. Gathering information from a variety of measurement systems in the centre enables more in-depth analysis.

In modern systems, it is possible combine several sensors into one measuring system, which enables the simultaneous recording of multiple physical values. Such an arrangement is called a microsystem or measuring *mote* (Fig. 1). [13] It may be fully autonomous and communicate with the central laboratory by using wireless connectivity.

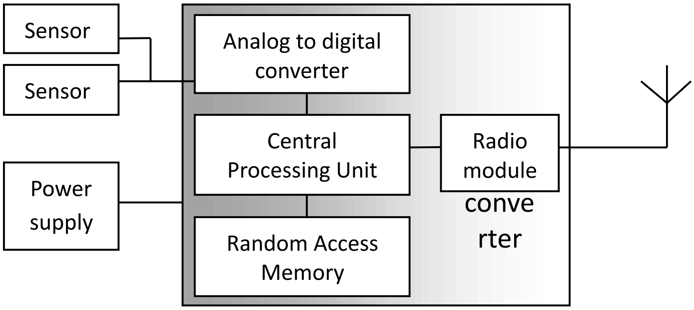

Fig. 1. Simplified diagram of a measuring microsystem (according to [13])

2. Monitoring of the phases of a building's service life (SL)

Monitoring – depending on needs – may be carried out at all stages of the service life project design, implementation, use and demolition.

During the development phase of the project, compliance with requirements on the project tab regarding properties during the period of use is controlled by, among other things. Moreover, the information describing the detailed design and other documents relevant to the assessment of the service life of the test results is checked and an evaluation of the performance of materials and components provided by the manufacturer is controlled. During the development of the project the completeness of the information concerning SAHP is also evaluated.

Monitoring at this stage means control of the development of the desired effects of the project, the comparison to the existing norms and technical specifications and standards as well, and, if necessary, taking indispensable corrective actions.

During the implementation phase the monitoring may refer to different aspects: the results of materials research (if carried out), changes in specifications and technical documentation, weather conditions, etc., In the case of work carried out during the winter, some construction processes require monitoring and evaluation of the regularity operations in real time. An example of where it is necessary to use continuous monitoring is concrete work, during which maintenance of the temperature and humidity of the setting concrete within well-defined borders is imperative [13]. Information about the possible need for revision of care activities is reported to supervisory centres in real time.

During the usage phase, the longest phase of the building's service life, monitoring is focused on certain types of potential construction risk (called Structural Health Monitoring, or – SHM) [1, 11]. The greater part of this research arises from the provisions of the law, such as the Ministry of Interior Regulations on the fire protection of buildings [10] or the regulation of the Minister of Infrastructure [9] introducing the obligation of monitoring in terms of the fulfilment of the conditions ensuring that borderline limit values for capacity and usage are not exceeded. The latter applies in particular to the regulation of buildings with rooms designed to accommodate a significant number of people, such as performing arts halls, sports arenas and exhibition grounds. This type of monitoring is carried out by specialized systems developed for this purpose [11, 13]. Monitoring systems, also known as warning alarm systems, are based on the results of measurements of the values of the condition of the building and its surroundings, or, more specifically, on information relevant to the type of potential threat. The greatest of these are the relative linear and angular displacements, temperature, strain, acceleration, and others. For most of these parameters permissible limit values – u_{dop} and borderline limit values u_{gr} (Fig. 2) should be determined. The permissible limit values (warning) are understood as those that do not directly threaten the safety of the design; exceeding them indicates the urgent need for the analysis of the causes of their emergence and prevention of further deterioration [12]. Exceeding the borderline limit values can pose the danger of collapse.

Demolition phase – this is the last stage in the service life of the building. Depending on the location of the building and the type of demolition, e.g. selective demolition, this work can be very dangerous and may require specific security measures and continuous monitoring.

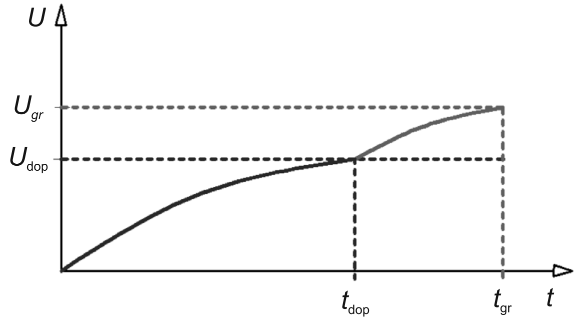

Fig. 2. Changes in value *u* as a function of time *t*

3. Monitoring of buildings undergoing refurbishment and modernisation

Refurbishment and modernization work concerns existing buildings up to several decades old. The aim of this work is renewal or adaptation to contemporary or new requirements: commercial, technical, environmental, production, etc. Often users of these buildings do not have any technical documentation; suitability for the intended use is assessed on the basis of individual exposure. Established theoretical models of construction upgrades are studied in actual working conditions by means of selected measurements of physical quantities, i.e. through monitoring.

3.1. Example 1. Monitoring test loads

The subject of this research is the construction of slab in an industrial building opened for use in 1972. The production line in this building was modernized. Three steel tanks with a capacity of 20 m^3 each were designated to replace existing 4-oak vats with a capacity of 12 m^3. The vats distributed load evenly on the slab, while the tanks distribute load in the form of concentrated forces; each tank is based on four supports. The investor has fragmentary construction documentation. Reinforcement in spans of load-bearing was established on the basis of the exposure. The strength of concrete was defined in sclerometric research. The results of static analysis indicate that the tanks with a capacity of 20 m^3 can be positioned on the floor in specific locations, as shown in Fig. 3.

Before submitting the upgraded technological line, the designers of the project citied the execution of test loads as an absolute condition. The comparison of measured strains of designated points with theoretical values would determine whether the assumptions regarding the calculations were relevant to real conditions.

The test load consisted of filling the tanks with water and measuring, at specified intervals, the deformation of slab elements. From static analysis, it appears that the greatest deflection occurs at the back of the tanks; the deflection in the rib marked '1' is approximately 7.6 mm [7].

Measuring points in the form of mirrors located in certain places on the slab. Under every measuring point in the basement floor, benchmark bases were located. Four measuring points were installed. Their location is marked on Fig. 3 with numbers '1', '2', '3' and '4'. Altitude measurements were made using tacheometry methods. The difference in the distance between the ‘mirror’ benchmark, mounted in the tested element, and the base benchmark was determined during two different measuring periods; before filling the tanks and during the subsequent phases of filling indicating the increase in the deformation of the tested element, i.e. ribs.

The test load was carried out according to the following course of action:

– filling tank *Z*1 wit water,
– taking readings of the deformation at measuring points,
– filling tank *Z*3 situated at the adjacent grid,
– filling tank 2 and measuring strain,
– waiting 24 hours and re measuring the deformation,
– emptying all of the tanks and measuring the deformations.
– The results of the measurements are shown in the following table.

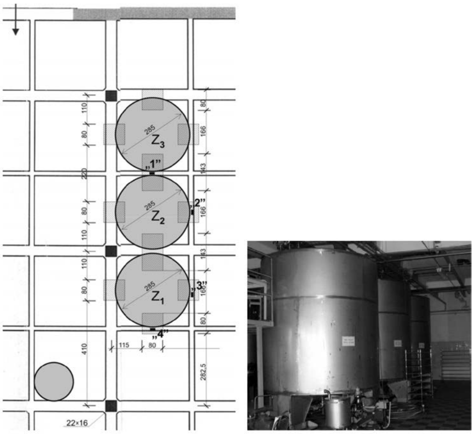

Fig. 3. The proposed schema of location tanks. View of the tanks positioned on the slab

Table 1

The extent of deformation of measuring points of structural elements of the slab[mm]

State of tanks	Measuring points				Date of measurement
	‚1’	‚2’	‚3’	‚4’	
All emptied	0.0	0.0	0.0	0.0	14 January
FIlled Z_1	0.1	0.3	0.8	1.0	15 January
Filled Z_3 (Z_1 also)	1.2	1.8	1.1	1.0	16 January
Filled Z_2 (Z_1 i Z_3 also)	1.7	2.0	1.5	1.2	17 January
All filled	1.7	1.9	1.6	1.5	18 January
All emptied	0.2	0.3	0.8	0.3	19 January

The extent of the distortion in the test of structural elements in the slab is definitely less than that specified on the basis of numerical analysis. At point '1' the maximum deflection was 1.7 mm. These data show that the assumptions for the analysis were correctly made and indicate the maintenance of a significant level of safety of the slab structure. The basis for a positive evaluation of the suitability of the structure subjected to a test –load is the confirmation of the assumption about the elastic behavior of the structure [6]. This is indicated by the fact that a slight deflection of the assets remained after removing the test load. At point '1' the permanent deflection was 0.2 mm. The location of the tanks on the slab given the current technical condition of the structure will not cause a threat to its integrity.

3.2. Example no. 2. Monitoringof deformation while securing the foundations of public utility building

The subject of research is building C-4, concerning a five-storey basement, located in the complex of classroom buildings of AGH in Cracow. The design layout of the building is oblong: full ceramic brick walls, thick-ribbed slabs. The building was opened for use in the 1960s. In its immediate vicinity there is a new building, the Energy Centre (C.E.) which was under construction at the time of writing (Fig. 4). C.E. comprised of five floors above ground, and one underground. The level of the foundation of the newly designed building is approximately 250 cm below the bottom of the footing of C-4. Before the start of the excavations under the widely-spaced foundations of the new building, securing work along the top wall of the existing building C-4 was carried out. Fig. 5 shows a cross-section of the foundations of both buildings. This work was carried out by the 'jet grouting' method – that is, injection jetting consisting of mixing the soil with grout and extruding it under high pressure. The project provided for the execution of about 80 injection columns. The following parameters of the injection process were assumed:

- Drilling diameter of 114 mm to 150 mm,
- Grout density of 1.46 g/cm^3 to 1.61 g/cm^3 (c/w from 1.0 to 1.5),
- Compression medium to a pressure of 350–400 atm,
- Lath lifting speed from 4 cm/7 to 4 cm/3s,
- Length of the column: – 12–14 m,
- Spacing of columns: – 600 mm.

The columns were carried out in so-called floating order; i.e. every 4th column in a row was injected, with no more than 5 columns completed per day. This „order" was intended to minimise the effect of short-term loosening of land until the binding of the grout injection.

Due to the complexity of the C-4 building work, monitoring was undertaken. In the basement level and the ground 8 benchmarks were mounted. The location of these benchmarks is shown in Fig. 4. In the technical design of the C.E. building, the permissible deformation of foundations was defined as: $u_{\mathrm{dop}} = 20$ mm.

In the first phase of the protective work, the following foundation-pile parameters were assumed: injection pressure $p_{in} = 300$ at, forming a single pile – $t_{\mathrm{in}} = 15$ min. During the protective work measurements of the deformation of the walls were taken in every 24 hours.

After completing approximately 26 piles, a 'push' of the foundation of building C-4 was observed. The maximum deformation measured at benchmark no. 5 was $u_5 = \sim 20$ mm. At the same time, visible scratched appeared on the longitudinal walls (Fig. 6). After analysing the results of previous monitoring and consultation with the design office, it was decided that the parameters for completing the remaining columns were to be changed: $p_{in} = 250$ at, forming time– $t_{in} = 40$ min. Subsequent readings of deformation of the benchmarks confirmed the validity of the decision: the deformation of the walls decreased; at the end of the protective work the deformation at benchmark no. 5 was: $u_5 = 12$ mm. Ten months after the end of work it was $u_5 = 5$ mm, i.e. less than u_{dop}.

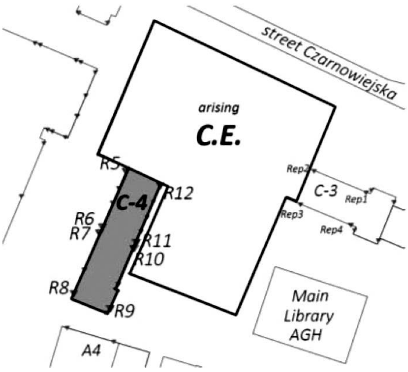

Fig 4. Projected position of buildings C-4 and C.E. *Ri* – benchmark number

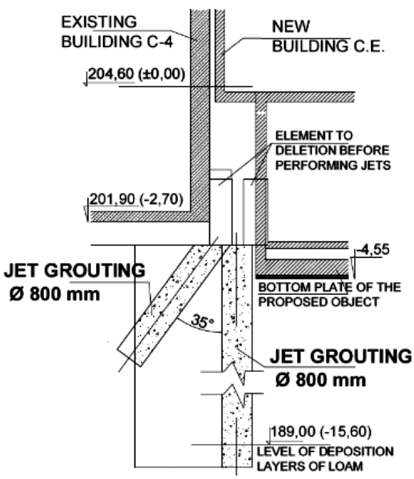

Fig 5. Cross-section of the foundation of buildings C-4 and C.E

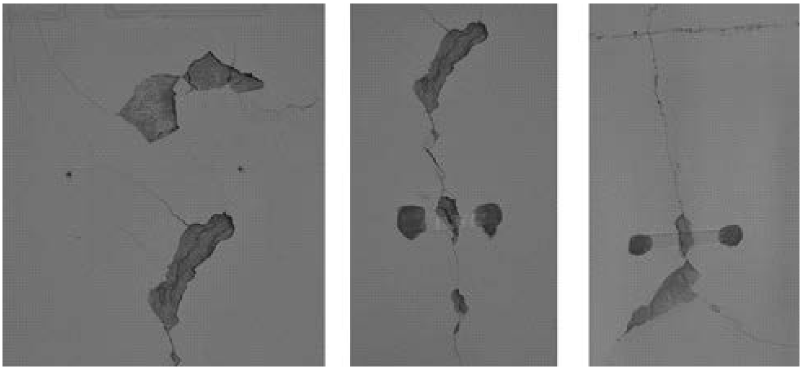

Fig. 6. Examples of visible scratched in C-4 building

4. Conclusions

During refurbishment work with limited design documentation available to the designer and, in particular, when refurbishment of a building is associated with an increase in usage parameters, the test-load of a structure and monitoring enable the deformation of the safety level of a building.

Problems associated with constructing buildings in areas with a dense downtown structure and the consequent, nature of impacts on adjacent buildings, the reasons for emergence of risks and ways to counter them are widely known. However, the individual character of each building, the variability of natural field conditions, related to geological-engineering and hydrogeological conditions and external environmental conditions mean that while erecting buildings, despite the care taken in the preparation of projects, we should anticipate unexpected reactions, as in example no. 2.

Based on an analysis of the results from the aforementioned examples, it can be concluded that the use of the monitoring enables the determination of the correctness of the assumptions in the proposed solution in real time, and, in the case of deviations, help in making appropriate decisions regarding further action.

Monitoring enables the updating of the assumptions, which in turn contributes to the safety of the monitored building.

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TECHNICAL TRANSACTIONS | **CZASOPISMO TECHNICZNE**
CIVIL ENGINEERING | BUDOWNICTWO

2-B/2014

TOMASZ BŁASZCZYŃSKI, MICHAŁ MAJCHEREK*

ECOLOGICAL CONSTRUCTION AND NEW TECHNOLOGY. DISCUSSION OF SOME TECHNOLOGICAL INNOVATIONS WHILE IMPROVING THE BUILDING'S PERFORMANCE

BUDOWNICTWO PROEKOLOGICZNE A NOWOŚCI TECHNOLOGICZNE. OMÓWIENIE WYBRANYCH NOWINEK TECHNOLOGICZNYCH PRZY POPRAWIANIU WŁAŚCIWOŚCI UŻYTKOWYCH BUDYNKU

A b s t r a c t

This paper is a collection of solutions, which when used in construction would allow for improvements in living conditions and reduce costs, while adhering to regulatory and consumer requirements. The proposals presented apply to single-family houses, tall buildings, but also entire urban agglomerations. There is also a multitude of solutions resulting from the revitalization of urban areas. All of the above is presented in terms of new technologies which support zero-energy and environmentally friendly construction.

Keywords: green construction, ecology, new technologies, non-standard design

S t r e s z c z e n i e

Praca stanowi zbiór rozwiązań, których wykorzystanie w budownictwie pozwala na poprawę warunków bytowych oraz obniżenie kosztów wynikających z przystosowania do rosnących wymagań prawnych oraz konsumenckich. Przedstawione propozycje dotyczą zarówno budynków jednorodzinnych, wysokich, jak i całych aglomeracji miejskich. Nie brakuje również rozwiązań wynikających z rewitalizacji obszarów zurbanizowanych. Wszystko pod kątem nowości technologicznych wspomagających budownictwo zeroenergetyczne i proekologiczne.

Słowa kluczowe: budownictwo zielone, ekologia, nowe technologie, nietypowe projekty

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1. Introduction

The modern construction industry faces many problems, most of which have appeared relatively recently, thanks to growing awareness and consumer expectations. Users don't just want their houses and apartments to be a place of accommodation, but they also want them to be a place to hide from the everyday hustle and bustle, a place for social meetings and for the education of their future children.

The second aspect, which cannot be overlooked in all modern facilities currently built is the energy issue, and more specifically, how much energy the building consumes during its life. Investing their entire savings, often accumulated over many years, the user needs to know if they can afford to maintain their dream house. This is even more important in the case of high-rise buildings, because the scale of the operating costs results from the number of companies occupying the building.

2. Energy deficits

An energy shortage could cripple an entire country. With the constantly growing demand on resources, the total paralysis of transport and communication is already a real threat. Meanwhile, commonly applied ways of generating energy are either harmful to the environment, or do not provide sufficient supply. It is therefore necessary, not only to generate energy, but also to find a better use the resources that we have. What's more, it is important to minimize transmission issues that generate additional costs.

Assuming pro-ecological solutions, every building is a potential source of savings. Changes in Polish regulations concerned with the thermal insulation of buildings are a good example. However, it is never possible to insulate a barrier completely. Any discontinuity such as ventilation, windows and door openings, cause heat losses. These, in turn, translate into operating costs. One way to solve this problem is recuperation; however, this raises a lot of controversy. The problem is the issue of the placement of individual rooms and their volume. This solution is not always cost-effective. Additional costs associated with annual maintenance do not improve the situation. Another issue is the education of residents who very often do not know how to properly ventilate the premises without large heat losses. An alternative might be to design a buffer space in the building to warm the rooms, while maintaining proper ventilation. This solution is all the more interesting, as it does not require the use of sophisticated technology, and the whole structure is based on the fundamental principles of physics. At the same time we need to pick the right solutions for a specific building.

However, irrespective of savings, energy consumption is steadily increasing. When looking for green energy sources, we can immediately see that a much more efficient solution is to obtain energy from the sun and wind. In this case we are dealing with dependence on the weather, but you can apply more than one panel or a turbine in a building. Specifically, the development in the field of solar cells allows for almost limitless architectural solutions, and with increasing performance, it is no longer necessary to cover the entire roof with panels. In turn, replacing classic wind turbines with vertical one minimizes solutions to only 0.5 m in height. These new designs can also be installed in places that were considered inaccessible until now (Fig. 1). The large tracts of flat industrial roofs, which generally are placed on open spaces, are particularly promising. Moreover, the weight of such turbines means they can also be mounted upon light structures, and the amount of electricity produced in this manner may be sufficient to power lighting. They are very efficient, use magnetic bearings and pose no threat to birds.

Fig. 1. An example of vertical turbine (source: http://www.folkecenter.net)

Fig. 2. Philips Blossom lamp (source: http://www.worldchanging.com)

However, there are more possibilities. Philips has developed a design for Blossom smart solar lamps, also equipped with wind turbines (Fig. 2). This type of element can decide whether it is able to get more energy out of wind or the sun, and adjusts to the most efficient position. Moreover, the use of LED lamps led to a significant reduction in energy consumption at night, when they have the task of illuminating the streets. The special paving, which generates energy by pressure, is also noteworthy. Installing these panels around a bus or tram stop can produce sufficient electricity to light it through the night. Savings will be enormous, given the amount of such shelters exist in each major city.

There are many more similar solutions. Separately, they hardly have a serious impact on the energy balance, but together they help to create a smart home system that uses every possible way to produce and save of valuable energy.

The savings in terms of energy can be found not only in the exploitation of a building, but also in all stages of its existence. Thus, when designing and building we should pay special attention to the materials used, their production, origin, and location in the facility. Everything completed according to sustainable development. The very concept of sustainability doesn't only apply to the ecological aspect (which, however, appears most frequently in the press), but also to issues arising from social and economic relationships. Achieving the "golden mean" between these three aspects must occur in such a way as to guarantee free development not only in the present, but also in the future for the next generations.

3. Floating structures

The world has a limited land suitable for casual building. Land only occupies 29.8% of our planet's surface, and even then there are a lot of mountainous areas or regions deprived of normal conditions for life and growth. It therefore became necessary to search for new solutions to deal with this issue.

The first solution, already used in some areas on a large scale is the construction of artificial islands. The most picturesque examples of this type of construction can be seen in Dubai, where the Palm Island project includes a set of the World's largest artificial islands. Their surface is so large that it allowed for the construction of airports, hotels and high-rise buildings. This unusual design, however, is still dependent on the substrate and its position relative to the sea. Although this is a solution, it also requires constant monitoring, mainly due to surging water, which constantly erodes the first couple of meters. Another problem may be the level of the sea is systematically increasing due to melting glaciers, therefore projects such as Palm Island remain a temporary solution.

Due to this situation, it might make sense to make better use of areas already inhabited. The consequence of such thinking results in building higher, and then the problem may be the materials themselves.

Thus, it became necessary to find a solution that would allow builders independence from soil. As it turns out, this was not that difficult. Based on the fundamental laws of physics, it was possible to create the first floating structures, which incidentally have also been established in Poland. Unfortunately, Polish construction law remains a problem because of the lack of foundations, which are an integral part of the design. Meanwhile, floating homes are already being created on a large scale in the Netherlands, where not only are they popular, but there are also areas in which no different type of buildings can be erected. This primarily involves all kinds of flood zones, located along the major rivers and lakes. In case of an emergency situation or a flood, the house just drifts in place, safely anchored to prevent it from floating away.

Fig. 3. A model of the Lily Pad floating complex (source: http://www.powrotnik.eu)

Most importantly, these do not have to be small buildings. Some of the houses can compete with free-standing houses in terms of their clever design and size. Interestingly, there are even designs for high-rise buildings equipped with drifting systems. However, this is not a complete solution. If designers can create designs for floating buildings with a significant number of floors, then bolder designs might also be completed.

This notion is confirmed by the Lily Pad project, which, as the name suggests, comes from a great water lily leaf, easily able to support a person's weight (Fig. 3). Lily Pad not only can support a person, but it is a floating district with its own sources of renewable energy, filtration systems and water recovery systems. Furthermore, it also uses biologically active partitions in the form of green walls combined with wind turbines of various sizes, adapted to the wind force. Furthermore, the very structure of the walls is varied and by rotation allows for the adjustment of cool air flowing to the center of the complex from above the water. It is one of the first steps towards zero-energy housing and self-sufficient cities.

4. Biologically active partitions

One of the leading trends in the twenty-first century is the revitalization of urban areas. Large poorly designed developments with cramped buildings characterized by poor living conditions and poor efficiency. These developments tend to have a higher perceived temperature associated with heat radiation and heat reflectivity from the smooth surfaces of such buildings. These are so-called Urban Heat Islands (Fig. 4). Another threat is the air pollution including greenhouse gases and fly ash. Information about standards being exceeded several times, which prevent taking children for a walk, shows an example of how serious this issue is.

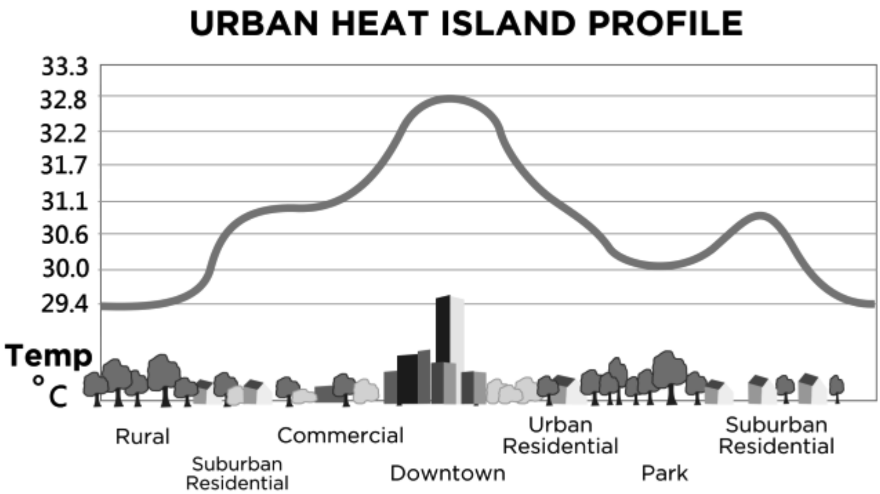

Fig. 4. Urban heat island (source: http://www.wikipedia.org)

To fight such a strong pollution, we should not only reduce the number of vehicles, because they are not the only cause of the production of exhaust gases, but also introduce as many green urban areas as possible. Unfortunately, at this point we would face the issue of the required undeveloped space, which might become a basis for a park or square with plants. This is impossible to achieve in most cities. In turn, only creating green areas in the suburbs does not solve the problem. We have to find another solution that will save space, while introducing a significant amount of green.

The solution lies in green roofs and green walls (Fig. 5). These form large expanses of green, which are isolated from the rest of the structure and allow for a changing the level of humidity and reduces pollution. In addition, it is also the perfect sound-absorbing surface to fight another threat of the present day – noise.

In contrast to solar panels or wind turbines, their use should be adapted to the climate in which such barrier is to be built. We also have a wide variety of structures, which can be used depending on the dimensions of the building and the additional loads that the structure can transfer. These solutions can also be used selectively on parts of the roof or facade; therefore it in no way limits the vision of the architect, who can integrate green areas according to their vision.

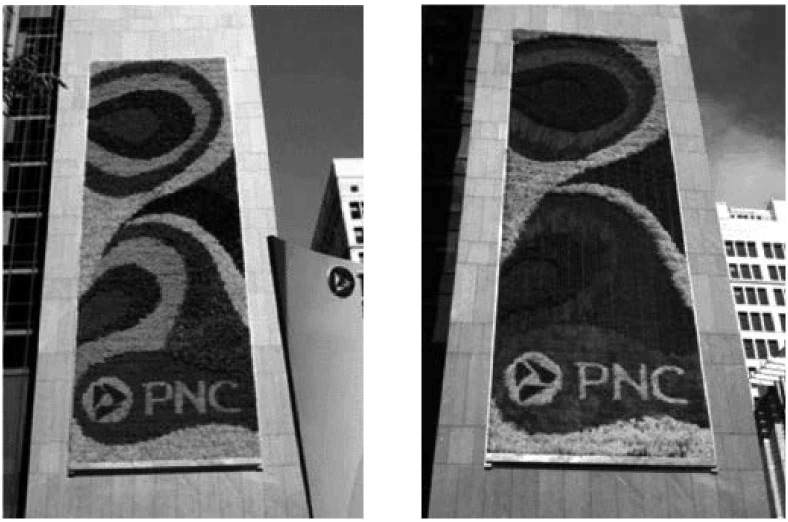

Fig. 5. Green wall and its evolution throughout the year (source: https://www.pnc.com/)

It must also be noted that these structures can also be used inside buildings, creating interesting interior elements and guaranteeing comfort to users. Green panels are ideally suited as natural air filters, which are able to lower the temperature by two to three degrees Celsius. It has also been proven that the presence of vegetation has a positive effect on the user's mood. We also should also consider impact on the environment. The use of green walls and green roofs on a larger number of buildings could change the microclimate around the city, helping to improve the air quality and living conditions.

5. Zero-energy buildings and cities

This is just one of the variants of our future, and in part also our present. However, zero-energy balance does not mean lack of power, but the ability of a building or complex of objects to produce the at least the amount of energy required for its operation. This only means that the building does not have any additional consumption beyond systems which are self-contained. This type of building not only uses solar panels and turbines, but also geothermal sources, biogas processing plants, as well as recuperation. In suitable areas, you can take advantage of the proximity of rivers, or the ocean. This can be complete with additional options, such as modern types of self-cleaning windows, or biomechanical coatings that respond to the intensity of solar radiation by adjusting the surface tension to the amount of light and heat supplied through the barriers. The proper deployment of rooms and vegetation relative to the compass can lead to a situation, in which buildings will not need air conditioning systems. This, however, again characterizes solutions for people who know how to benefit from them.

The Clay Fields project showed exactly how important the education of users is. It is a passive social housing estate, the main objective of which is to assume a low cost of construction along with the use of biodegradable materials found in the vicinity of the construction site. This minimizes transport costs and also reduces the production of emissions. As for the residents, they were carefully instructed when to open the selected windows and in what order to minimize heat losses while ventilating. Indeed, the proper use has allowed reducing operating costs appreciably. And this is still merely a passive house.

Fig. 6. Masdar – bird's-eye view (source: http://www.fosterandpartners.com)

While applying a similar method in more modern designs, one should keep in mind that an eco-friendly building does not depend solely on the conditions of use, or the raw materials used. It is also a matter of logistics of the entire project, its implementation, clean-up, and therefore the whole life of the building, from the creation of the design through its operation and future demolition and recycling.

The importance of the zero-energy building issue is best presented by countries that have already started the construction of such facilities, which include: The United States, China, Germany, Ireland, Canada, Norway, Sweden, and the United Kingdom. In fact, the list is much longer, and also includes Poland. It all boils down to using the solutions applied in specific projects, on an industrial scale. For this reason, more attention is paid to modular solutions, which are much cheaper to produce than individual projects, even though they are not always very picturesque.

Thus, all possible issues related to energy and emissions have been taken into account in the Masdar City (Fig. 6) a design by the Norman Foster architectural studio on behalf of the Emir of Abu Dhabi. It is a leading indicator of pro-environmental thinking in the world in which even machines are powered by solar energy. The project in its simplicity does not assume many extremely futuristic solutions, but it is the very scale of the solution which makes it interesting; it is to occupy an area of 6 km^2. Besides solar energy produced here in the largest quantities in the world, the city will also use geothermal sources, as well as additional systems to be integrated, which include water treatment and recycling systems, smart umbrellas for protection against the sun, which open depending on the level of sunlight, water floating turbines off the coast, and finally a compact, low development that primarily assumes walking and cycling. There is also a solar powered public transport system. In addition, the city will process all waste, providing an almost one hundred per cent recycling, and carbon dioxide is to be filtered and collected in special chambers where it had been formed, preventing the emission into the atmosphere. This creation has been under development since 2006, but the details of some of the solutions are changing along with the project, constantly improved and developed. An additional indicator of the grand scale with which the whole project is implemented may be presented by the open fund created towards the construction of this fully self-contained city – $ 300 billion. The projected earnings, related not only to the complex, but also advances in solar cell technology accompanying the whole project are estimated to be at least twice that amount.

6. Expectations and reality

Most of the solutions presented above are still futuristic and despite excellent assumptions, require a lot of effort and funds in order to be realized. It is therefore necessary to create appropriate development strategies. A perfect example of this might be “Europe 2020” which demonstrates the basics of sustainable construction, improving the quality of lives and investment in technology. For skeptics, this may seem like a utopia, but in reality, it is possible to achieve. Meanwhile, Malmö in Sweden has become the first energy independent city in Europe. Here total energy production comes from renewable sources with public transport is implemented through bicycles and buses powered by biofuels. Interestingly, it is a self-sufficient structure, but still has a connection to the general net, allowing for the donation of the excess of generated energy to be used by other entities. In this way it is possible to use the full potential, while maintaining the economic balance.

It should be noted that producing devices intended to collect excess energy is exceptionally expensive, therefore efficient use of such devices requires proper planning in order to fully benefit from the energy they produce throughout the whole year.

In order to achieve this educating the user will be a vital pre-condition.

By increasing the environmental awareness of users, it has been proved that it is already possible to make savings in the consumption of water, electricity and gas. Campaigns for turning off the water while brushing your teeth, is a small example of what we should strive for. It should be noted that such changes still require a lot of time.

7. Reduction of CO_2

The European Union is currently pushing through policies aimed at rapidly cutting down the level of CO_2 emissions across the region: "Concretely, the Union has set five ambitious objectives – on employment, innovation, education, social inclusion and climate/energy – to be reached by 2020. Each Member State has adopted its own national targets in each of these areas. Concrete actions at EU and national levels underpin the strategy". These words, spoken by President José Manuel.

Currently however, a forced reduction of CO_2 emissions, could lead to an economic crisis, companies would not be capable of rapid reorganization of all workstations and machines. A complete reduction may require another 20 years, however, this does not mean the abandonment of ecological thinking, on the contrary, sustainable development is a long-term action, to ensure appropriate conditions of many generations.

Firstly we should take the differences requirements of various regions into account. Thus, the assessment of the effectiveness of the proposed solutions should be carried out by scientific groups from different fields of science, industry and economics, specifying which of them will get a reduction in harmful emissions or to arrange jobs needed to sustain proper economic development. Construction as one of the largest sectors of the economy must also be subject to these changes.

In accordance with taking all aspects generating expenditures related to using resource and energy into account, it was necessary to use complex computing systems based on multi-criteria evaluation. The hardest part of the implementation has been, and it still is proper reflection parameters, each of which expresses a different unit. Currently known systems are LEED (U.S.), BREEAM (United Kingdom), DGNB (Germany) and HQE (France). However, in Poland, the most popular are the LEED and BREEAM systems. The DGNB system is also starting to only gain recognition in Poland. The list of solutions also includes other forms of certification (often dedicated to specific countries). Currently, the LEED and BREEAM systems are recognizable brands in more than 120 countries around the world, created dedicated programs (in the way of understanding and negotiation), which can be described as regional programs. An example of this is LEED in Canada or LEED in Poland. In this way it is possible to take individual aspects related to the geographical location, climate, or the mentality of society into account. Although individual assessment systems differ in many respects, such as the method of administration result of the evaluation, the scope and accuracy criteria and the nature of the buildings for which they are intended, they still have similar mechanisms of action. What was initially targeting only aspects related to saving energy, now also includes broad sociological aspects, referring to comfort and what was already mentioned, to education. The same points in the evaluation of gains for gray water circuits, rational distribution of spaces, large exposure objects, or adaptation of the roof slope to the needs of biologically active partitions. But most importantly, all certification systems are constantly changing, according to technological and economic development.

8. Conclusions

To sum up, environmentally-friendly solutions in the construction industry, are not isolated projects or technologies, but a combination of factors that cooperate in a proper configuration capable of achieving a higher standard of living and a positive energy balance. The benefits for man and environment are still relatively low, especially in economic terms. However, we cannot abandon ecological thinking, as with further development of the currently promoted solutions, it will be possible to improve the performance of individual systems, which over time can make our buildings (not only residential ones) self-sufficient. How serious the matter is can be seen at every step, with subsequent climate changes and the images of degraded natural environments. To protect our future, we should start with small solutions, because they are what make sublime projects possible.

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PLANNING PROBLEMS OF CONSTRUCTION PROJECTS PROGRESS

PROBLEMY PLANOWANIA PRZEBIEGU PRZEDSIĘWZIĘĆ BUDOWLANYCH

TECHNICAL TRANSACTIONS | **CZASOPISMO TECHNICZNE**
CIVIL ENGINEERING | BUDOWNICTWO

2-B/2014

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MODELLING OF NETWORK SCHEDULE INCLUDING PRIORITY OF SELECTED TECHNICAL RESOURCES

MODELOWANIE HARMONOGRAMU SIECIOWEGO Z UWZGLĘDNIENIEM PRIORYTETU WYBRANYCH ŚRODKÓW TECHNICZNYCH

A b s t r a c t

The paper presents a method of network planning CPM – Critical Path Method. The author compares models of optimal solutions to design deadlines for individual works, taking various leading technical resources such as is labor and a tower crane into account.

Keywords: network programming, optimization, technical resources

S t r e s z c z e n i e

W artykule przedstawiono metodę planowania sieciowego CPM – Metodę ścieżki krytycznej. Autorka ma na celu porównanie modeli optymalnych rozwiązań zaprojektowania terminów wykonania poszczególnych prac przy uwzględnieniu różnych wiodących środków technicznych czyli robocizny i żurawia wieżowego.

Słowa kluczowe: programowanie sieciowe, optymalizacja, środki techniczne

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1. Introduction

Scheduling is one of the most difficult stages of planning construction work. Planning completion is based primarily calculating the amount of work, the determination duration of each activity as well as the acceptance of work teams and the use of appropriate equipment. The article presents the problem of prioritizing leading resource. When two alternatives of works are compared: first leading is the tower crane, the second option leading is the workers. The author has applied a two-point planning network: Critical Path Method (CPM), because it best shows technological connections, design and actually reserves time. In [1, p. 91] The authors attempt to find the best solutions for managing design and implementation, and indicating that the CPM in the Polish reality is a good method, along with other tools, which complement each other and allow for a clearer presentation of the results.

2. Network Programming

2.1. The description of investment

The subject of the study is the construction of a multi-family building complex with a basement, consisting of nine apartments. The basement consists of six garages, storerooms and utility rooms. There are three apartments on each floor. The total building area is 290,50 m², 610,00 m² floor space, the gross cubature of 3312.00 m³, with the height of each building standing at 10.8 m. For the design, the residential building was located on the actual area. In the grounds there is a water feature, therefore, it was also necessary to apply a band drainage system. The ground is composed of small and medium-sized thickened humus sand.

2.2. Works plots

The plot is divided into building sections of approximate size, on which the same combinations of processes were carried out.

The property was divided into works plots in the elevation view, separating each floor as a separate plot and in the plan view along the stairs. This was possible thanks to the repeatability of processes and approximate mirrored workload on each of the plots.

2.3. The organization of work [2]

The key step in the planning works is the choice of work organization method [2, 3]. The most popular are the following organizational methods: the method of further completion, the method of simultaneous completion and the method of even work. The first of these is a method of organization, in which all operations are carried out in sequence – one after the other on each work place. The method of simultaneous completion consists of carrying out the work simultaneously at all working areas. And the even working method is the optimal method combining features of the two previously described methods. In the present building used an individual method of work organization based on the even working method, due to work on the tower crane leading.

Work planning should begin by calculating the primary labor and equipment investment. Calculations were performed using the *Norma Pro computer program*. According to the tables of workload (based on [4]) the total number of shifts (excluding the number of employees) amounted to 1744. The tower crane amounted to 80.7 shifts. It is necessary to determine the number of working hours of both workers technical equipment. The working brigade/ crew should then be set as the number of workers assigned to the activity as well as determining the number of pieces of equipment. On the basis of the assigned brigades/ crews and pieces of equipment, it can then be determined how many shifts activity will take. This information is also supplemented by sufficient knowledge of manufacturing technology in order to begin the network planning. It is also necessary to make a graph of technological connections between operations. The network structure is as follows: preliminary works, earth works and foundation were planned in succession, then the brigade/ crew was separated into two plots from ground floor construction until final execution of the project. a screenshot of the network model shown on figure 1. and the selected fragment shown on Fig. 2.

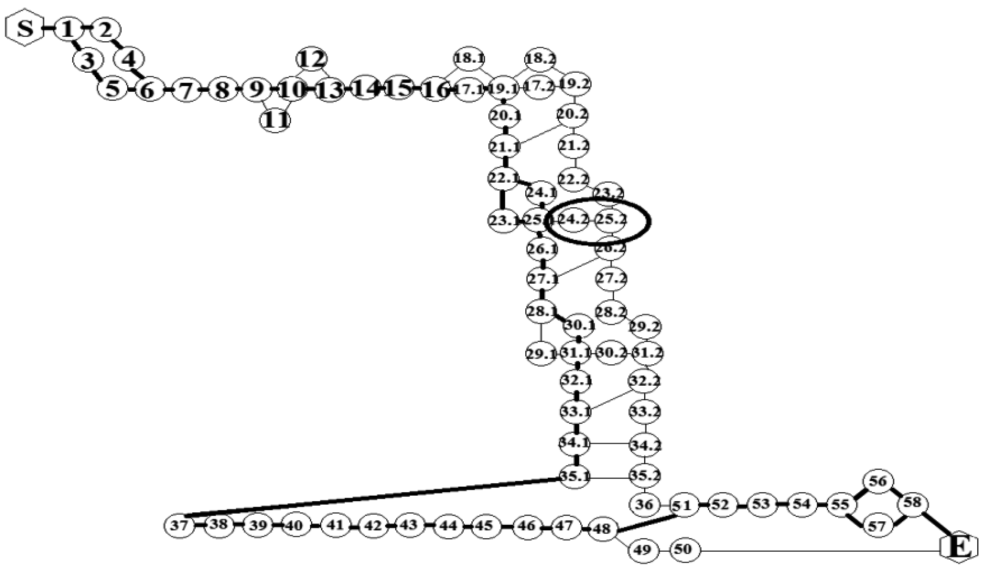

Fig. 1. Screenshot of the whole enterprise network, taking into account the priority of the tower crane with indicated fragment presented in Fig. 2 (elaborated by author)

In CPM beginning and ending working operations should be distinguished. All operations must be linked technologically, which means that every action must have its predecessor "preceding operations" and the successor "subsequent operations". Operations in the graph are marked by arrows, events by circles. The fragment of the network model shown in Fig. 2. Actual operations are marked by a solid line, and the apparent operations such as technological gaps, transition work teams are marked by a breaking line. For each event, two different times need to be distinguished: the earliest possible date of the event and the latest permissible date for the occurrence of the event. The difference between these terms is the time reserve "backlash" of the event. If the reserve is equal to zero or tends towards zero, then the event is critical. Zero time reserve should be interpreted as the operations lying on the critical path that are determined by the due date of beginning and completion of operation. It cannot be moved either forward or backward, as this would affect date of completion of all works. Operations that are not critical can be completed with the displacement equal to the time reserve and it does not affect the deadline of the works. Precise backlash is presented in section 3.1 and 3.2.

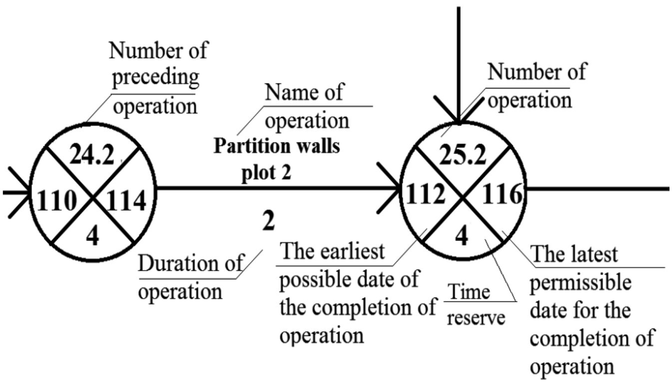

Fig. 2. Fragment the network schedule of execution objective building (elaborated by author)

2.4. Technical resources

Technical resources consist of renewable and non-renewable [3]:

- Work – the designer sets the specialized work teams or professionals of the specific field, determines the number of people needed to perform the work and creates a list of workers' labor, called the graph of employment, work is a renewable resource;
- Work equipment – necessary for the transport of materials and completion of works. Most commonly used are the following: means of transport, earth moving equipment (an excavator, a bulldozer, a grader), a concrete pump, a crane, a lift, a winch, a scaffolding etc., hardware is renewable resource;
- Work materials – materials of the required quality and quantities are calculated in excess or in estimate by KNR [4] directories. For each type of material is given a directory unit, for example for concrete [m3], steel [t], etc., materials are a non-renewable resource.

Depending on the leading technical equipment, the duration of work can vary. If for the completion of a construction project a construction team is employed and divided into brigades/teams, it is obvious that the number of employed persons must be constant. It cannot be scheduled work for one day for the 12 workers and another day for the 16 workers, because it is uneconomical and unfair to employees. Works should be planned in such way that a fixed number of workers have continuous employment without interruption (except those resulting from technological interruptions). The priority of labor is easy to plan, but difficult to reconcile with the optimal use of the equipment.

Construction materials do not affect the duration of the works, provided that they meet the quality requirements, quantities are properly estimated and they are delivered on time.

Taking construction equipment into consideration, it is always possible to determine the leading equipment. For each step, the main equipment is determined, for which the time of work becomes a determinant of the duration of the operation. The priority of the leading equipment operation can be set and it can be assumed that the operating time of a machine should be selected in such a way that the machine does not have any major downtime – in order to have the highest possible efficiency. This has its advantages – the equipment is used in maximum as much as possible, the time of its work is minimized, and the cost of operating this equipment also is reduced relatively to the schedule without considering the priority equipment. The next chapter describes the selection of technical means priority which is labor and crane work.

3. Works optimization [5]

3.1. Priority of the tower crane

The work of tower crane was analyzed. The aim of the study was to verify the use of the working time of that hardware and to plan works in such a way that the equipment is used to a maximum, to ensure the highest operating efficiency of the crane and to minimize time. The characteristic parameters required for the equipment need to be determined in order to optimally select a machine.

Regarding the selected crane, after calculating the necessary indicators and performance while working on various operations, the following parameters were provided: load capacity max is 1.8 t, overhang 22 m, height under hook 19 m.

In the case of the priority operation of the tower crane, it was necessary to establish the following work teams: preliminary and earth works: 6 workers, the foundations: 6 workers, the construction of the basement to the ceiling: 6–8 workers, the construction of the ground floor to the ceiling: 5–8 workers, construction floor to the ceiling: 5–8 workers, the construction of the second floor to the ceiling: 5–8 workers and completion: 8 workers. The number of workers has been selected in such a way that the crane was used to its maximum.

The equipment analyzed by the author will be used for the preparatory works: zero state work and assembly. Operations in which the crane was needed are summarized. The crane will be used, among other tasks, during the lifting of pallets of hollow bricks, ceiling beams, light equipment such as welding equipment and a plastering machine. In order to optimally use this equipment, the sequence of operations carried out during the construction of the building were set in such a way that works using the crane were carried out in very short intervals. This action meant that the assumptions of even work methods will not always be met. However, thanks to this, the crane will be used for a period of 30 to 171 shifts, all of the work were scheduled for 174 shifts (which is not equal to the calendar days, due to the assumption of non-working holidays). The start date of the project established on 03.01.2010 and 26.11.2010 on completion of the works, of course taking into account holidays and days free from work. Calculated deadlines for execution and reserve of time for the following: 10 shifts reserved for the ceiling over ground floor for the second plot, 4 shifts reserved for the ceiling over first floor for the second plot, 10 shifts reserved for the ceiling over second floor, and 10 shifts for sheet metal treatment.

Based on the number of working shifts adopted by the initial schedule and machine shifts set in the workload tables, the percentage of use of the tower crane was calculated. The results are shown in Fig. 3. The axis X shows only those operations that employed the analyzed technical resource, the Y axis is the percentage ratio of the possibilities for using the crane.

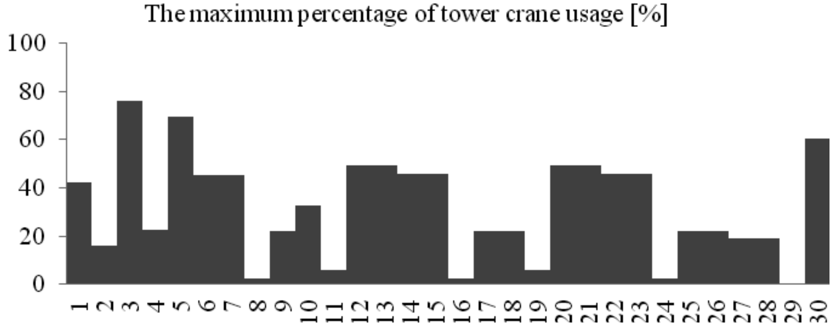

Fig. 3. The maximum percentage of tower crane usage – *y* defined for the integrated operations, *x* axis presents numbers of integrated operations (elaborated by author)

The calculation of Tangible Directory Expenditures [4] during the network model shows that in a few days, i.e. from 30 to 33 shifts, at shift 72 and from shifts 95 to 98, the crane possibilities would be exceeded. This means that the equipment would have to work more than 8 hours in a single shift on those shifts. This is not possible in the assumptions of one shift daily, therefore other methods for solving the problem were explored. One is to rent an additional crane for the duration of the non-availability, while another possibility is to change the date, during which the crane would still be available at crucial moments, while pouring the ground floor and brick work to the walls on the ground and first floors. There is also the possibility of employing additional workers, which could help speed up operations.

Eventually, the problem of deficit was solved using various methods in order to avoid the use of an additional crane. Instead of five employees pouring on the ground floor, 9 were hired, resulting in the operation being completed earlier. The partition walls on the second works on the ground floor and second floors will also be bricked sooner as a result. The partition walls on the second works plot on the first floor will, however be bricked later than assumed in the schedule, at the same time the stairs will be poured on the second floor, it is from 104 to 108 shifts.

3.2. The workers priority

In order to maximize crane efficiency during the construction, it has to be assumed that the correct number of specialized workers will be available for every shift, because every shift has a different number of workers. Thus, this solution can't be applied to the construction of one freestanding house, but rather considered for the construction of an entire housing estate. This is the best solution because of the efficient use of working time and the cost of a tower crane, but it is not so good with regard to the employment of workers chart which will not be constant, as is required for such a construction. Therefore a second schedule was established, which incorporated a fixed number of workers and a team of 8 people. Thanks to that works were scheduled for 155 shifts. The start date of the project was established for 03.01.2010 and to end on 29.10.2010, of course taking holidays and days free from work into account. This means that with such a schedule, construction of the multi-family building would take less time. The chart of employment will be constant, but the efficiency of technical resource such as the crane will not be at maximum efficiency, which means that all the possibilities will not be used. In the case of a leading work, it was necessary to maintain a constant number of jobs: preliminary and earth works: 6 workers, the foundations: 6 workers, the construction of the basement to the ceiling: 8 workers, the construction of the ground floor to the ceiling: 8 workers, construction floor to the ceiling: 8 workers, the construction of the second floor to the ceiling: 8 workers and the completion of works: 8 workers.

Calculated deadlines of execution and reserve of time. In the present case time reserve only relate to the completion works: plaster, painting, flooring for the second plot.

3.3. The selection of the optimal solution (5–7)

Optimization is a series of actions to be taken during design work, in order to reach the best solution according to the selected criteria. The purpose of optimization can be, for example, the minimization of costs, execution time, or maximizing quality or profit. The search for the optimal solution is quite a problematic task, especially considering the many factors which have to be taken into account, which in fact often translate into mutually exclusive conditions assumed in the project. In practice, this means that an optimal solution may not exist, but still, every effort has to be made to pursue it. Such an example is the case analyzed in this article, when the time-optimized operation of the crane excludes the optimal employment of workers and vice versa. Here an intermediate solution will no longer be the best and is not optimal. The author in her analysis did not take costs into account, because the simplest solution would be to plan the work in the cheapest way, and as such, was not a research problem. The aim was to analyse the comparative for the case of maximum use of the crane as well as the more obvious constant work graph, which is the basis of an even working method**.** The critical path method used in this article is very good for providing opportunities to save time. Even the author in [6] writes that this method provides good results as regards cost analysis.

4. Conclusions

Network programming aims to plan works in order to show technological relationships, the duration of these operations and their earliest and latest dates of completion. The more criteria optimization is taken into account, the harder it is to determine the best solution in this regard. Another problem may be unforeseen events, that could disrupt the planned time schedule, such as damage to equipment, not supplying materials in a timely manner, adverse weather conditions, and many others, which confronted other author's mentioned in this article.

It has been concluded that scheduling is a complex process consisting of a series necessary decisions to be made at the design stage [7]. One way to protect against failure is to present optimal solutions together with alternative solutions, but this requires additional work. a very good solution is to schedule the work in the specified and individual manner for the specific construction work. This involves among other things, the calculation of all parameters for specific equipment, in order that operating efficiency can be determined accurately. The supply of earth and materials, distance, efficiency of vehicles and proper design of the development site should also be taken into account. It is most important to ensure that the implementation of these projects and plans will take place. Unfortunately, at the moment they are not given a great importance, as is evident by the results of a survey conducted on 30 employees from different construction companies (elaborated by author): only 28% of respondents claim that they fully use time schedules in their enterprises, where 65% point as a reason for failure for meeting the deadline for completion of work as bad weather or the delayed delivery of materials.

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A CONCISE REVIEW OF METHODS OF CONSTRUCTION WORKS DURATION ASSESMENT

SYNTETYCZNY PRZEGLĄD METOD OKREŚLANIA CZASU REALIZACJI ROBÓT BUDOWLANYCH

A b s t r a c t

This paper presents a concise review of some methods and techniques that are used for assessing how long construction works (namely – activities or work tasks in terms of programming) will take. As background for the discussion, some definitions are given and preliminary remarks are made. Chosen methods and techniques for the assessing of construction works duration are presented and briefly discussed. Additionally, some results from the author's initial research on the construction works duration are presented.

Keywords: construction works duration

S t r e s z c z e n i e

W artykule przedstawiono zwięzły przegląd niektórych metod i technik, które są wykorzystywane do oceny, czasu realizacji robót budowlanych (w podziale na zadania harmonogramu). Jako tło i wprowadzenie do dyskusji przedstawiono uwagi wstępnej definicje związane z omawianą problematyką. Zaprezentowano i krótko omówiono wybrane metody i techniki oszacowań czasu realizacji robót budowlanych. W artykule przedstawiono i wykorzystano w analizach wyniki obserwacji czasu realizacji wybranych robot budowlanych.

Słowa kluczowe: czas realizacji robót budowlanych

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1. Introduction

The Construction projects need planning to provide success in terms of time, cost and quality. It is therefore expected that construction projects will be completed within an accepted time, on budget and with the expected level of quality. Project planning is performed at different stages, at different levels and by different participants of the project. According to Cooke and Williams [3] project planning during the design stage and project planning during the construction stage can be distinguished. Considering levels and participants of a project [3]: project planning is carried out by the client/project manager, pre-tender planning is carried out by the tendering contractors, pre-contract planning is carried out by the main contractor and contract planning is carried out by the main contractor and subcontractors may be mentioned.

According to Hendrickson and Au [4]: „Construction planning is a fundamental and challenging activity in the management and execution of construction projects. It involves the choice of technology, the definition of work tasks, estimation of the required resources and durations for individual tasks, and the identification of any interactions among the different work tasks".

The thoughtful and reasonable planning process of a construction project should involve some general steps. A logical approach involves [3]: getting a feel for the project, establishing the key project dates, establishing the key activities or events, assessing how long these activities will take, establishing the sequence and deciding which programming technique to use.

In this paper it is the author focuses on one of the most important steps of the construction planning process – that is construction works duration assesment. Durations of activities (which correspond to scopes of construction works according to accepted division of the whole project) form the essential information for programming and scheduling. Adequate assessment enables a planner (or a team of planners) to prepare a realistic model for the execution of construction works in terms of time.

2. Definitions and preliminary remarks

Activities in terms of construction planning are the operations or processes that occur in the course of a construction project which consume both time and resources [2] (in some cases they may consume time only). Other terms commonly used are: „task" or „work task". The terms „work tasks" or "activities" are often used interchangeably in construction plans to refer to specific, defined items of work [4].

Programmes may be defined as [2]: a statement of a plan or some part or detail in positive terms in words and diagrams. Breaking a construction project down leads to definition of a component parts derived from the whole scope of construction works. This may also be a work breakdown structure which includes different levels of information aggregation, in other words, component parts may be ordered through a hierarchical structure. Breaking down a construction project should allow for a reasonably accurate estimate of activity durations and the required resources (compare Hend and Au [4]).

Activities that are defined as basic components of a construction programme should meet some fundamental needs [2]:

- they describe as fully as the information allows, the scope of works of the project,
- each activity must be independently capable of having a duration and when necessary a resource requirement ascribed to it,

- they must be capable of being used to provide the adequate monitoring of progress,
- they must be significant, having regard to the purpose of the programme.

A duration in terms of construction planning may be defined as [2] the time required or available for the completion of an activity. All durations must be expressed in a common unit of working time. Depending on the information aggregation which is adopted for different levels of work breakdown, structure units of working time are working hours, working days, working weeks etc.

During the construction stage of the project resources, that are necessary to complete a certain scope of works can be considered (according to Marcinkowski [6]) as passive or active. One can define building materials, construction products, construction members, prefabricated elements etc as passive recources, while workers and construction equipment, construction machines etc can be described as active. Active resources are especially important in construction planning as their effort is measured with working time influencing the effect of a specific production [6].

3. Different approaches to assessing construction works duration

Any assesment of activities duration for the purposes of planning a construction needs some input information (compare [2]):

- work breakdown structure of a project including a list of activities (work tasks),
- adopted construction technologies for certain activities (methods of execution to be adopted),
- quantities of construction works covered by each activity,
- information about active resources employed by the activity and production rates of that resource.

According to a guide published by the CIOB [2] a duration may be derived by calculation, quotation or assesment:

- calculation – an arithmetical calculation based on the known quantities or units and the production rates for the resources to be used,
- quotation – use of a duration stipulated or obtained from a specialist source (especially in case of specialist work, construction pauses, manufacturing or delivery periods, commissioning or fitting out periods etc.),
- assessment – based on limited data or on experience from previous projects.

Other divisions of methods include [3] stresses on the availability of information:

- assessing duration activities based on judgement and experience – at the early stages of a project, when little information is available,
- calculations considering relationships between the quantity of work and the anticipated output or rate of production – when detailed information about the project has been provided.

Połoński [7] takes other criteria into consideration and mentions three possibilities for assessing the duration of activities:

- assessed duration is deterministic,
- duration is assessed by the use of a technique adopted for PERT analysis and beta – optimistic, pesimistic and most probable durations are assessed,
- duration is considered by use of probability distribution (e.g. normal, lognormal, tringular) and its parameters.

All authors who have considered the problem of assessing construction works duration agree that the anticipated output of production is essential for calculations of the time required for the activities (and thus construction works). This information may be expressed in many different manners as: production rate of an active resources, productivity of a standard crew, time required to complete a unit of work (reciprocal of productivity or production rate).

This information can be obtained from different sources e.g.: feedback from previous projects, data gathered and processed by the contractors (and subcontractors), work studies carried out by contractors (and subcotractors), accepted published data, specialist advice. (Data gathered by contractors and subcontractors or the effects of their work studies, which are usually restricted for internal use only).

4. Chosen methods of construction works duration calculation

4.1. Methods used for deterministic duration assessment

Basic formulas adopted for assesing how long the activities will take are presented by Cooke and Williams [3]:

$$\frac{\text{Quantity}}{\text{Output\_per\_hour}} = \text{Hours} \tag{1}$$

$$\frac{\text{Hours}}{\text{Number\_of\_hours\_per\_day}} = \text{Days} \tag{2}$$

$$\frac{\text{Days}}{\text{Number\_of\_days\_per\_week}} = \text{Week} \tag{3}$$

In the formulas above duration expressed in hours (1), days (2) or weeks (3) is actualy calculated on the same basis of known quantities of construction works and anticipated output.

According to Hendrickson and Au – the estimation of activity durations may be based on historical records of particular activities and their average durations. „Since the scope of activities are unlikely to be identical between different projects, unit productivity rates are typically employed for this purpose [4]". The following formulas correspond with this approach:

$$D = \frac{A}{PN} \tag{4}$$

where:

- D – duration of an activity,
- A – quantity of a certain construction task – number of measurement units calculated for a certain construction task,
- P – the average productivity rate of a standard crew for a certain construction work (measured in number of measurement units per working hour),
- N – the number of crews assigned to the task.

Other option is to use unit production time which is a reciprocal of *P*:

$$D = \frac{TA}{N} \tag{5}$$

where:

T – the time required to complete a unit of work by a standard crew (measured in working hours per measurment unit of a certain construction work).

4.2. PERT method and use of probabilistic distributions

PERT is a commonly known method of project analysis where the durations of activities are estimated with the probabilistic beta distribution method. The beta distribution method is used to characterize activity durations, since it can have an absolute minimum and an absolute maximum of possible duration times.[4] Assuming the duration time of an activity is a random variable *t*, a stands for absolute minimum and *b* stands for absolute maximum – the form of the density function for $t \in \langle a; b \rangle$ is given below [1]:

$$f(t) = \frac{1}{\beta(p,q)(b-a)^{p+q-1}}(t-a)^{p-1}(b-t)^{q-1} \tag{6}$$

where:

$$\beta(p,q) = \int_0^1 x^{p-1}(1-x)^{q-1}\,dx \tag{7}$$

Consequently the distribution curve depends on the parameters p and q. (Series of transformations are explained in details by Cyunel and Biernacki [1]). Assessment of activity duration with use of beta distribution requires in practice three parameters – optimistic duration (absolute minimum), most likely duration and pessimistic duration (absolute maximum) which are essential for this approach. For the purpose of the analysis of mean duration t_e can be calculated as a weighted average where three parameters a, m and b are present:

$$t_e = \frac{a + 4m + b}{6} \tag{8}$$

where:

a – optimistic duration of an activity,
m – most likely duration of an activity,
b – pessimistic duration of an activity.

(In the formula (8) weights of the parameters for a, m and b are equal 1, 4 and 1 respectively. These are the default weights. However different values of weights may be applied according to the skewness of the distribution).

To allow for uncertainty in activity duration, other probabilistic distributions can be applied. An activity duration might be assumed to be a normal distributed or a triangular distributed random variable. The probability of experiencing a particular activity duration is taken into account (compare [4]). Normal distribution is easy to work with, as it only needs two parameters (it is often used as an approximation of beta distribution). The biggest advantage of triangular distribution is that it only needs three values to be unambiguously determined: minimum value, most likely value and maximum value of random variable [5]. The form of the density function for triangular distribution for $t \in <a; b>$ is given below:

$$f(t) = \begin{cases} \dfrac{2(t-a)}{(b-a)(m-a)}, t \in < a; m) \\ \{ \quad \dfrac{2}{(b-a)}, t = m \\ \dfrac{2(b-t)}{(b-a)(b-m)}, t - (m; b > \end{cases} \tag{9}$$

where:

a, m, b – defined exactly the same as in equation (8).

(Apart from the distributions introduced above, application of other distribution types such as uniform, lognormal, Student's t – distribution is also possible – as presented in the literature on the subject).

5. Examples of duration assessment for chosen type of construction works

Plastering works have been chosen as an example for construction work analysis, for the application of the methods described above. Technological assumptions for the plastering works are:

- type of plaster – one coat gypsum plaster applied to walls, concrete substrate,
- method of application of a plaster – with use of a mechanical plastering machine,
- building type – residential, multistorey buildings.

Assumed quantity of a plastering works equals to 2500 m^2. It was assumed that the standard crew consists of four workers and the number of working hours per day equals to 8.

5.1. Application of methods for deterministic duration assessment

Duration assessment was based on two types of sources of information:

- published information – widely available (in Poland) cataloged information regarding the normative consumption of a resources necessary for different construction works,
- observations which were carried out by the author during his practices on construction sites for two different subcontractors (subcontractors are marked here as A and B).

On the basis of this published information [8] it was assumed that the normative time required to complete a unit of the plastering work equals to 0.319 w-h/m^2. Thus the normative productivity is 1/0.319 = 3.135 m²/w-h. The productivity of a standard crew: P = 4*3.135*8 = 100.3 m²/w-h. On the basis of these observations, for subcontractor A (the first three and the last two of twelve observations are shown in the table 1) it was calculated that the average productivity rate for a single worker equals to 3.6 m²/w-h, (sample standard deviation calculated respectively equals 0.308). Productivity for a standard crew: P = 4*3.6*8 = 116.0 m²/day. (As the number of workers in a crew was changing at the time of the observations the average crew productivity was not taken into account).

Table 1

Observations of the durations of plastering works – subcontractor A

No.	Number of workers in a crew	Hours per day	Number of days	Measured output [m²]	Time required to complete a unit of work by a single worker [w-h/ m²]	Time required to complete a unit of work by a crew [w-h/ m²]	Measured productivity of a single worker [m²/w-h]	Measured productivity of a crew [m²/w-h]
1	4	8	3	392.5	0.245	0.061	4.1	16.4
2	3	8	4	342.0	0.281	0.094	3.6	10.7
3	4	8	3	378.5	0.254	0.063	3.9	15.8
…	…	…	…	…	…	…	…	…
11	3	8	3	244.5	0.294	0.098	3.4	10.2
12	4	9	2	234.0	0.308	0.077	3.3	13.0

On the basis of observations for a subcontractor B (the first three and the last two of ten observations are shown in the table 1 are shown in the table 2) – average productivity for a single worker is equal to 3.0 m²/w-h (sample standard deviation calculated respectively equals 0.163). Productivity for a standard crew P = 4*3.0*8 = 96.0 m²/day. (As the number of workers in a crew was changing at the time of the observations the average productivity of a crew was not taken into account).

It is easy to notice that productivity for a standard crew and thus the durations presented in the table 4 differ quite significantly. Observations for subcontractor A allow for the assumption of the shortest duration, whilst observations for subcontractor B allow for assumption of the longest duration. Published information gives the assessments in between.

Table 2

Observations of the durations of plastering works – subcontractor B

No.	Number of workers in a crew	Hours per day	Number of days	Measured output [m^2]	Time required to complete a unit of work by a single worker [w-h/ m^2]	Time required to complete a unit of work by a crew [w-h/ m^2]	Measured productivity of a single worker [m^2/w-h]	Measured productivity of a crew [m^2/w-h]
1	4	8	3	302.5	0.317	0.079	3.2	12.6
2	4	9	3	321.5	0.336	0.084	3.0	11.9
3	3	9	4	332.5	0.325	0.108	3.1	9.2
…	…	…	…	…	…	…	…	…
9	4	10	2	214.5	0.373	0.093	2.7	10.7
10	5	8	3	358.5	0.335	0.067	3.0	14.9

Comparison of durations assessed with use of equation numbers (4) is presented in the Table 3.

Table 3

Assessed durations of plastering works (assumed quantity 2500 m^2)

Source of information	Productivity for a standard crew P	Assessed duration D	
		Number of crews $N = 1$	Number of crews $N = 2$
Observations – subcontractor A	116.0 m^2/day	21.55 ~ 22 days	10.76 ~ 11 days
Published information [8]	100.3 m^2/day	24.92 ~ 25 days	12.46 ~ 12 days
Observations – subcontractor B	96.0 m^2/day	26.04 ~ 26 days	13.02 ~ 13 days

5.2. Application of triangular distribution for duration assessment

For the observations presented in tables 3 and 4 triangular distribution of activity duration was approximated. On the basis of the information shown in the tables 3 and 4, necessary durations to complete assumed quantity (2500 m^2) of a plaster were calculated at first. Each of the observations was a basis for a calculation – thus for subcontractor A , the author obtained 12 results and consequently for subcontractor B – 10 results. Due to the inconsistencies in number of days and number of workers in the crew, the results were calculated on the basis of adjusted productivity of a crew per day. The results of this approximation are presented in the figure 1. In the graphs, the horizontal axes represent assessed durations t_i (results of calculations were rounded up to full days), the vertical axes represent the reciprocal of frequency of t_i.

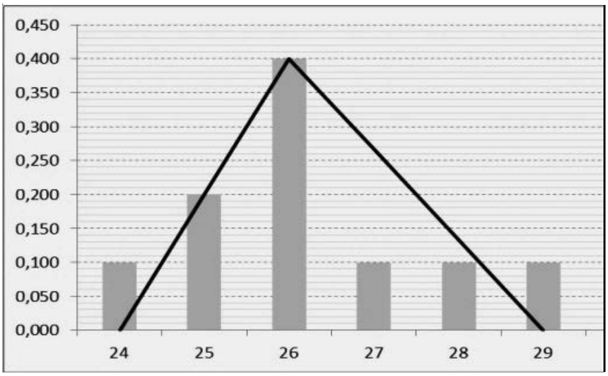

Fig.1. Approximation of duration distribution with use of triangular distribution on the basis of – a) observations made for subcontractor A; b) observations made for subcontractor B.

Estimated parameters (as explained in subsection 4.2) of the distribution: $\hat{a}$, $\hat{m}$ and $\hat{b}$ as well as $\hat{t}_B$ (expected value) and (standard deviation) are set together in the Table 4.

Table 4

Parameter estimates of triangular distribution of a plastering works duration

Basis of approximation – observations	$\hat{a} = \min\{t_1, t_2, \ldots, t_n\}$	$\hat{m} = \mathrm{mode}\{t_1, t_2, \ldots, t_n\}$	$\hat{b} = \max\{t_1, t_2, \ldots, t_n\}$	$\hat{t}_\tau$	$\hat{\sigma}$
– subcontractor A	19	21	25	21.7	1.247
– subcontractor B	24	26	29	26.3	1.027

(Despite the small cardinality of observations which constituted a basis for the assessments of durations, for the purpose of the approximation of triangular distributions, the analysis of correctness of fit was based on the ‘chi-square test’. To make this possible it was assumed that the density function for parameters a and b took values higher than zero – but still close to zero. Chi-test values were $p = 0.0328$ for the approximation shown in Fig. 1a) and $p = 0.0014$ for the approximation shown in Fig. 1b). These results indicate a good fit of distributions as $p < 0.05$, however, these results must be treated with caution due to the aforementioned small cardinality of the observations).

6. Conclusions

The methods presented in the paper correspond with the problem of construction works duration assessment. Durations may be assessed either as deterministic values or described with probabilistic distributions.

In the case of methods applied for the assessment of deterministic durations, the results depend on the choice of information source. The analysis shown in the paper reveals differences in durations assessed for exemplary construction works (namely plastering works) based on published sources and observations carried out for two different subcontractors. Differences in such calculations may be caused by several factors such as: skills and qualifications of workers, demanded quality of completed construction works, organizational constraints etc. Any assessment regarding duration may therefore require some adjustments.

Work studies carried out for specific performers (workers, crews, contractors) are helpful when they include the inter-individual variability in duration assessments.

The application of probabilistic distributions allows the inconsistencies in durations, which may result from inconsistencies in productivity, changing situation in the construction site or other randomly appearing factors. Use of probabilistic distributions may be helpful in more advanced analysis concerning durations of construction works (for example risk analysis). However, if probabilistic distribution is applied to represent activities durations (that is durations of certain scopes of construction works) the problem is increased since one must apply statistic methods, moreover usually three parameters are required.

It is the author's intention is to continue the research and to compare the durations assessments made on the basis of different probabilistic distribution types.

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BEATA GRZYL, ADAM KRISTOWSKI*

A CALCULATION PROPOSAL OF LABOUR TIME INPUT WHEN CONCRETING IN DIFFICULT ATMOSPHERIC CONDITIONS

PROPOZYCJA WYZNACZENIA NAKŁADÓW CZASU PRACY PODCZAS BETONOWANIA W TRUDNYCH WARUNKACH ATMOSFERYCZNYCH

A b s t r a c t

The paper presents a selected proposal of establishing labour input in concreting jobs carried out in difficult atmospheric conditions. The author aims to answer the following question: is there a common-sense limit, e.g. defined by temperature, to which concreting works can be performed safely and efficiently and beyond which it is more reasonable to stop the work and wait for more favourable weather conditions.

Keywords: construction, planning

S t r e s z c z e n i e

W artykule przedstawiono wybraną propozycję wyznaczenia robocizny robót betonowych wykonywanych w trudnych warunkach atmosferycznych. W tym zakresie autor stara się odpowiedzieć na pytanie: czy jest granica określona np. przez temperaturę, do której możemy w sposób bezpieczny i ekonomiczny prowadzić roboty betonowe, a powyżej której lepiej jest je przerwać i poczekać na sprzyjającą pogodę.

Słowa kluczowe:

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1. Introduction

When undertaking concreting works in lower temperatures, one has to consider the need for technological steps which will allow the freshly poured concrete to cure in conditions as close as possible to the norm, for its durability to increase steadily and for the concrete to obtain that required durability before freezing. In order that the above conditions are met, four methods are generally used to cure and protect young concrete [1]:
– mix modification method,
– heat treatment method,
– heat preservation method,
– heated shelters method.

Among the mix modification methods, the following can be distinguished: chemical admixtures which speed up the process of binding, hardening, those which reduce batch water, air-entraining admixtures, chemicals enhancing plasticity, using higher brand cements or higher hydration cements, increasing the amount of cement, reducing the water-cement ratio to the lowest possible value, re vibration, introduction of improvements to eliminate the cooling of concrete during transport. The heat treatment method means providing additional heat by warming with hot air, steam, or with electrical devices. The heat preservation method involves using foil plastic insulation covers, Styrofoam or mineral wool, etc., in order to retain cement hydration heat. The heated shelter method requires complete insulation of the site from external factors.

Even though protection methods have been known and used for many years, the construction market lacks industry standards which would allow one to estimate the extent of labour input in difficult weather conditions. The Instruction [1], widely known in the construction community in Poland, lists some techniques to protect concreting works in high or low temperatures, but realistically speaking, nobody is able to calculate the exact cost of these protective measures. According to [1] – among others – low temperatures are assumed to be temperatures below 10°C while high temperatures are those that exceed 25°C. On the basis of his own professional experience in this respect, the author attempts to answer this question: is there a common-sense limit, e.g. defined by temperature, up to which concreting works can be performed safely and effectively, and above or below which it is more advisable to stop the work and wait for better weather. One has to be prepared for this kind of situation as a prerequisite of construction work planning [2]. Such readiness is costly and usually affects the contractor's profits. That is probably why many contractors take the risk and perform concreting works in unfavourable weather, counting on their good luck. Unfortunately, good luck is not something to be relied on and the consequences of failure are acute and concern mainly poor quality of the construction made, which in turn results in an avalanche of claims from investor supervisors and further financial problems.

2. Establishing the extent of the change of concreting labour time according to ambient temperature

Concreting works carried out at lower temperatures require an increased labour input and are additionally charged with the risk of compromising the quality of the elements produced. One ought to remember that it is relatively difficult to protect a construction from the cold on site since techniques successfully employed in prefabrication plants cannot be used out of doors. Therefore, it seems advisable to carry out an analysis of possible protection methods for selected construction elements. The analyses made by the author are based on individual calculations or research carried out on the natural scale, concerning concreting labour time and costs. For the purpose of this paper, the author presents results concerning two selected construction elements, typical solutions in monolithic building construction. Calculations for a reinforced concrete partition (Tab. 1) and reinforced concrete roof slab (Tab. 2).

2.1. Calculation for making a reinforced concrete partition

The main assumptions made for the purpose of calculating the cost of producing a reinforced concrete partition in low temperatures:

- partition capacity 17 m^3, surface area 55 m^2,
- Portland cement-based concrete, class C20/25,
- cost assessment for using a given method in air temperature of –10°C so that the concrete obtains sufficient durability and the construction can be used safely.

Table 1

Cost calculation results for producing 1 m^3 of concrete construction in –10°C

Method description	Cost of protection for 1 m^3 of mix [PLN]	Cost of protection with traditional formwork for 1 m^3 of mix [PLN]	Cost of protection with proprietary formwork for 1 m^3 of mix [PLN]
Concrete admixtures	PLN 47,23	PLN 673,21	PLN 1.229,43
Hot concrete mix	PLN 39,84	PLN 635,23	PLN 1.182,20
Hot mix and thermal insulation Styrofoam 10 cm	PLN 157,41	PLN 853,24	PLN 1.400,00
Hot mix and heated shelter	heater PLN 37,14 heated shelter PLN 105,73	PLN 1.236,24	PLN 1.721,15
Hot mix and heating mats	heating mats PLN 1.795,43	PLN 2.385,72	PLN 2.730,23

2.2. Calculation for making a reinforced concrete roof slab

Concreting labour cost calculations for building a monolithic 100 m^2 roof slab of C20/25 concrete where the slab thickness is 18 cm. The total amount of concrete used will be 25 m^3, while the amount of cast reinforcement has been omitted from the analysis.

Table 2

Cost calculation results for producing 100 m^2 of concrete roof slab

Atmospheric conditions	Suggested method	Additional input	Total cost of concreting labour [PLN]
ambient temperature above 25°C	using cement with lower heat of hydration, intensive moisture care	pouring water on concrete while it cures	PLN 29.517,11
temperature from 10 to 25°C	no additional labour input	none	PLN 24.367,31
ambient temperature 10 to 5°C	using a typical mix according to the project, extending the time in which elements are kept in the formwork	none	PLN 30.305,21
ambient temperature –3 to –10°C	using a concrete mix heated to 20°C with plastificator, making thermal insulation of 10cm thick Styrofoam for the concrete surface	C20/25 concrete with plastificator, heated to 20°C, Styrofoam sheets	PLN 34.277,98
ambient temperature below –20°C	using a concrete mix heated to 20°C, heating concrete with electricity, concreting works carried out in a heated shelter	C20/*25* concrete with plastificator, heated to 20°C, heated shelters construction, heater, insulated heating core, electricity	PLN 70.484,32

3. Summary

The methods presented were based on assumptions which allow one to calculate a mix temperature decrease during the curing process depending on the outdoor temperature and the type of formwork and insulation used, etc. On the basis of these calculations and research it can be said that making reinforced concrete constructions in winter at mean air temperatures below –10°C is uneconomical. In such cases, the thermal properties of the formwork are such that they lead to relatively quick heat loss from the concrete. When it comes to expenses, using construction chemicals alone is an advantageous solution as it is slightly more expensive than, for example, heating the concrete mix. Using formwork with additional Styrofoam insulation on the outside [4] is undoubtedly cost-effective for contractors who own this sort of construction; otherwise mounting and dismounting heating constructions each time may prove unprofitable [3]. A cost analysis for using heated shelters with a heating system shows this method is the least economical and is also expensive. The presented in Table 1 do not include the price of purchasing the heating system. The author is inclined to state that the traditional heated shelter method is justifiable for repetitive construction projects. The method which involves the use of warming mats may, in the author's opinion, be the most profitable among the methods presented in this paper, possibly resulting from the fact that warming mats lend themselves to repeated use, which is not accounted for in Table 2.

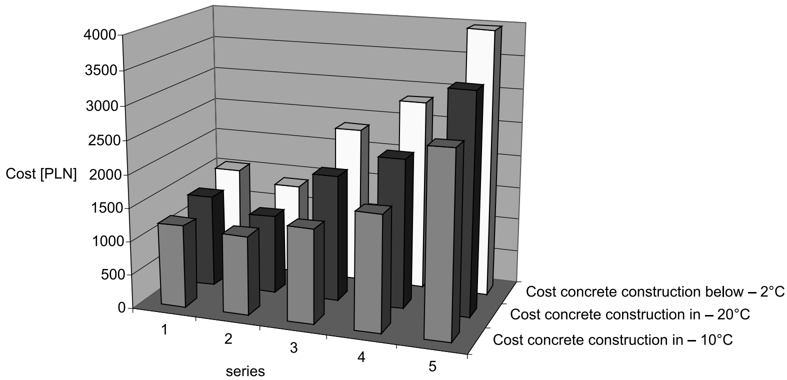

Fig. 1 Cost calculation results for producing 1 m^3 of concrete construction in –10°C, –20°C and below –20°C (series: 1– Concrete admixtures, 2 – Hot concrete mix, 3 – Hot mix and thermal insulation, 4 – Hot mix and heated shelter, 5 – Hot mix and heating mats)

4. Conclusions

The author has presented selected methods employed during concreting works, mainly used in wintertime. The availability and accessibility of the construction materials market enables the contractor to choose solutions best suited to expected weather conditions, according to the extent of the work to be carried out, expectations and financial resources. A definite limit of concreting works profitability cannot be established since they have to be calculated separately each time and an attempt should be made to choose methods which will prove best in each particular case, e.g. depending on the distance from a batching plant, repetitiveness of concrete elements, etc. While solutions which enable the curing of concrete in low temperatures exist, it may well appear that the profitability limit is set e.g. by the factor of human tolerance of low temperatures rather than technology. However, it can be said that in the case of meteorological conditions suitable for carrying out concreting works, a decrease in temperature will involve an increase of labour input at the following rates (based on Fig. 1): up to 30% for temperatures of 0 to –10°C, up to 150% for temperatures of –10 to –20°C, up to 250% for temperatures –20°C and below.

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ANNA KRAWCZYŃSKA-PIECHNA*

A CONCEPT OF AN INTEGRATED CONSTRUCTION PLANNING SYSTEM INVOLVING LOCATION-BASED SCHEDULING TECHNIQUE

KONCEPCJA ZINTEGROWANEGO SYSTEMU PLANOWANIA PRZEDSIĘWZIĘĆ WYKORZYSTUJĄCA TECHNIKĘ LBS

Abstract

This paper concerns an integrated construction planning method which combines both BIM and location-based management and scheduling techniques. The methodology of 5D planning and LB(M)S is explained using appropriate examples. Location-based scheduling and management is an entirely new production system for construction. It uses locations as the container of project data as well as flow-line scheduling. The author believes it can be a powerful tool for schedule optimization, but still needs investigation regarding the scope of quantity takeoff methods and further improvements of a self-learning labor-demand data base.

Keywords: scheduling, location-based methods, multilevel planning

Streszczenie

W pracy opisano problem zintegrowanego planowania przedsięwzięć budowlanych. Opisano koncepcję systemu do harmonogramowania i oceny jakościowej otrzymanych rozwiązań. Jako główne narzędzie do inteligentnego harmonogramowania zaproponowano technikę LBS, opisując ją w kontekście efektywnego planowania prac i wykorzystania zasobów.

Słowa kluczowe: harmonogram, metoda LBS, zintegrowane planowanie przedsięwzięć

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1. Introduction

Technologically and organizationally effective construction planning plays a key role in the building planning process nowadays.

Technologically effective construction planning is strictly combined with a selection of the most appropriate technological solution (e.g. formwork or scaffolding system, material technology, set of machines, etc.) to complete the works. The planner selects the best matching solution by evaluating formerly defined technological criteria such as: solution's ergonomics, solution's repetitiveness, safety, durability, availability (e.g renting conditions) etc. This multi-criteria selection problem has often been the subject of previous papers [1, 2], where both Electre Tri method as well as classifier ensembles incorporating AdaBoost algorithm were suggested to solve the decision problem.

A far more difficult issue is to plan building works effectively and assess schedule's quality properly. The planner should define work breakdown structures, working sections and sequences of work completion in order to:

- minimize durations of work,
- minimize costs generated by resources, required to complete each task,
- Increase efficiency.

The problem described above is associated closely with building technology, however, due to its complexity, it is not always possible to obtain a precise solution as scheduling and analyzing accessible resources at once is an analytically complicated problem. Therefore, solving the problem within computer simulations is highly recommended. As it is emphasized in [1], a reliable method or procedure, applicable to project planning, control and schedule improvement is much more desirable than obtaining only a certain sequence of activities to be performed. Such procedures should provide the planner with various acceptable solutions (i.e. schedules) and allow for their adjustment and evaluation through different criteria.

This paper recommends computer aided location-based scheduling and management techniques as part of an integrated, multi-stage scheduling system that allows the planner to control and amend the schedule, and therefore improve building process effectiveness.

2. The idea of integrated planning system

2.1. A quick overview of scheduling methods

Within the last sixty years, numerous quantitative methods for project analysis and scheduling have been developed, documented and supported with computerization. Traditional scheduling methods, such as: CPM (Critical Path Method), RAMPS (Resource Allocation and Multi Project Scheduling), PERT (Program Evaluation and Review Technique), GERT (Graphical Evaluation and Review Technique) or TCM (Time couplings method) are called activity based methods (ABM) and they put emphasis on networks of discrete activities. Since the 50's – CPM and its later modifications mentioned above have proved to be powerful techniques used for scheduling complex and non-repetitive works. However, when consideration is given to high-rise buildings, pipelining, roads and other projects consisting of an on-site fabrication and involving continuous or repetitive works in different locations, scheduling appears to be more closely aligned to repetitive scheduling methods, such as LOB (Line of Balance) or LSM (Linear Scheduling Method) [3]. Despite the long history and promising potential of linear methods, they have gained little interest among planners, as for decades they have been just graphical and manual methods. CPM-based techniques, even though they are strongly supported with computer software, do not provide the planner with the possibility of optimizing resources directly – each change in work breakdown structure or size of sections (e.g. sections combining) indicates quantity take-off verification, tasks' time re-calculation and realignment of the scheduling model. This can bring about a discontinuous work pattern and finally drive down the quality and effectiveness of the schedule.

This is why the use of scheduling techniques based on locations, not activities, such as the Location-Based Scheduling (LBS) method by Kenley [4], are strongly suggested in this paper, as they are more applicable.

2.2. Integrated planning system concept

Location-based scheduling has mainly gained popularity in English-speaking countries like the US, Canada and Australia, but also in Finland, where it was integrated into a commercial software package DynaPoject™ in 2005 (later known as Control®).

The practical application of location-based management systems require a precise model of construction and therefore involve BIM (Building Information Modeling) techniques. 3D CAD planning is then the first stage of integrated construction planning.

Recent research on integrated building performance planning [5–8] concentrates on an efficient framework for planning and scheduling, which is an IT-like problem and should take more engineering aspects into account. The scheme below (Fig.1) presents the idea of an effective multilevel planning system. This is an author's modification of Shih-Ming Chen's proposal presented in [5], Monteiro's one – issued in [7], and Song's – presented in [6]. It includes author's remarks, which will be discussed in the present paper.

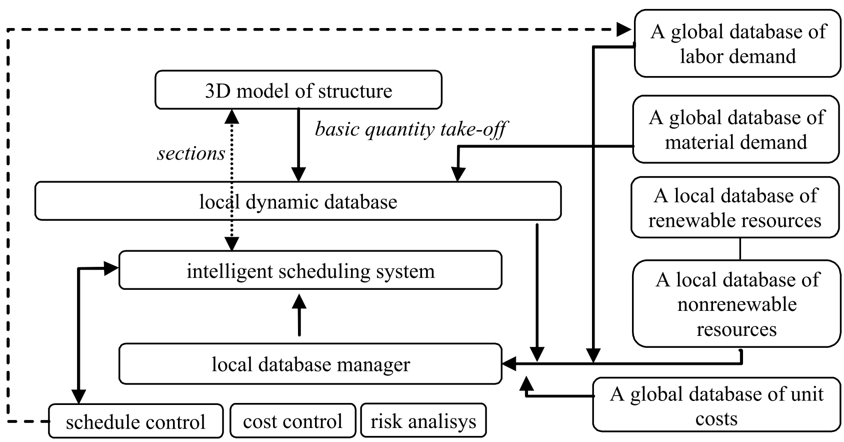

Fig. 1. The idea scheme of an effective multilevel planning system, author's elaboration

2.3. Intelligent scheduling (4D planning)

As we can see on the scheme, 3D CAD planning is the first stage of integrated construction planning. In the next step – a 4D model is created from the 3D CAD model by linking building components of construction with all specific activities to be performed. The planner then indicates sections (locations) and defines location breakdowns in the structure and automatically generates the basic quantity take-off (QTO).

Let D be the set of locations: $D=\{d_1,d_2,...,d_i,...,d_I\}$. Quantity of work k ($k = 1, 2, \dots, K_i$) to be performed in location d_i can be described within vector $\mathbf{S}^i=\left[s_1^i,s_2^i,...,s_k^i,...,s_{K_i}^i\right]$ (for i = 1, 2, …I). Unit labor demand for work k is defined within vector $\mathbf{R}^i=\left[r_1^i,r_2^i,...,r_k^i,...,r_{Ki}^i\right]$. The time of completion of work k in location d_i, noted t_k^i, should be calculated automatically form the formula (1):

$$t_k^i=\frac{p_k^i}{z_k^i}\quad (i=1,2,...,I), \tag{1}$$

where:

z_k^i – working crew available for work k on location (number of resources),

p_k^i – total labor demand (e.g. man-hours) of work k performed in location d_i, calculated within formula (2):

$$p_k^i=\sum_{k=1}^{K_i} r_k^i\cdot s_k^i\quad (i=1,2,...,I). \tag{2}$$

The data is then transferred to an intelligent scheduling system.

The location-based scheduling technique, that is recommended in the present elaboration, incorporates several layers of interactive CPM connections, which are combined into a 5-*layered logic* [3, 4]. Let's investigate the logic links:

Layer 1 – *an external logic* – includes logical relationships between works within locations; it is assumed that in each location, the logic link between the same works is similar. It simplifies the scheduling process. To create a link, typical to CPM connections, such as start-start, finish-start, etc. should be used.

Layer 2 – *an external higher level logic* – consists of the relationships between activities driven by different levels of accuracy. Each task should be allocated an accuracy level (the lowest level of locations which are relevant to the task) that corresponds to a hierarchy level in the location breakdown structure [4]. For example: *roof assembly* and *painting works* are to be performed at the same locations, one after another. According to layer 1 logic, after roof assembly in section 1, painting works should start. To start painting works after roof assembly in all locations, we create a proper layer 2 connection, which is shown on Fig. 2.

Layer 3 – *an internal logic between locations within activities* – is the most powerful tool in respect of resources' optimization, as it can ensure works' continuity. Layer 3 allows the planner to choose the task, which should be performed continuously as well as those tasks where the flow can be broken. It is explained in the following example (Fig. 3): earth works (*task A*) is a continuous task, while its successor – pipe installation (*task B*) is faster and discontinuous, which arises from ASAP start-finish relation between tasks. The planner can release the ASAP relation and make *task B* continuous, so it starts later but work is performed continuously, and in result there is no stoppage in work of a specialized crew.

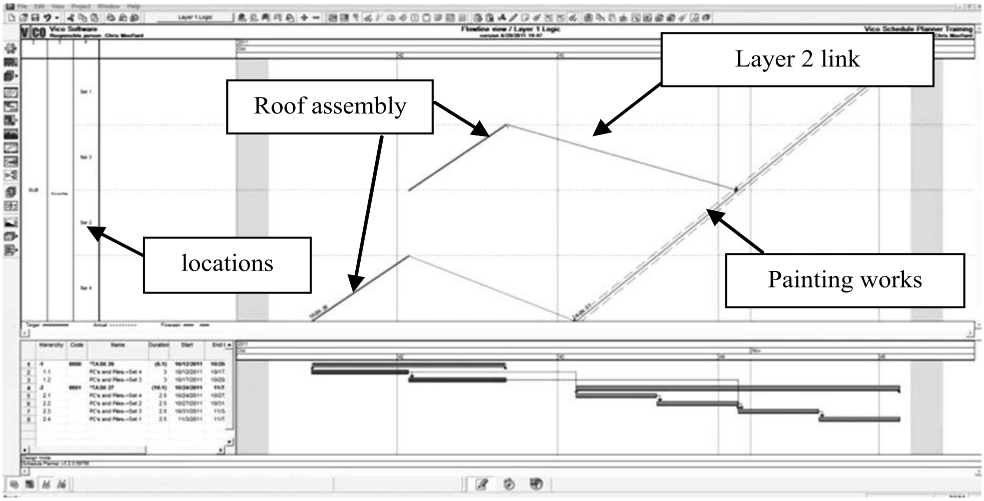

Fig. 2. An example of layer 2 logic link, *Vico software* window view

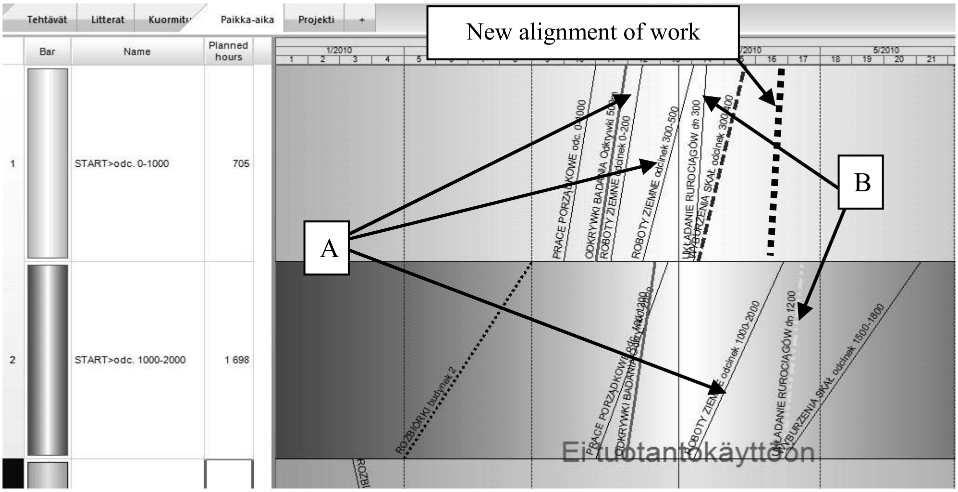

Fig. 3. An example of layer 3 logic links, *PlanMan Project 2012 demo* window view

Layer 4 is *a phased hybrid logic*, which is requires the creation of lags between locations [4]. The planner is able to establish location-lag, i.e. for concrete works executed in a multi-storey building. When casting floor n, it's not possible to perform any works (on that floor) n–1 and n–2 due to slab formwork construction. In such a case, the work can be continued freely on slab n–3, so with a lag of –2 floors, which should be defined in layer 4.

Layer 5 consists of other standard CPM relationships between any tasks and any locations; it can also be applied to the same task.

2.4. Schedule control and adjustment

After creating the schedule, let's consider the 5th level of the integrated planning process, which is a complex schedule for control and adjustment. It includes: schedule feasibility and predictability analysis, cost optimization, duration and risk trade-off and finally the optimization of resources' utilization.

According to Fig. 1, the schedule can be realigned in 3D and 4D models by: revising the bill of quantities and location breakdown structure, modifying location sequence of tasks, adjusting production rates by changing resources or scope of works, verifying unit labor demand, splitting tasks, making tasks continuous or discontinuous, deciding on the buffer size for each task.

An example of a schedule before and after realignment is shown on the flow-line charts in Fig. 4 and Fig. 5. Discontinous task C (Fig. 4) is made continous, which affects later start of task D (Fig. 5). The production rate of task A is simultaneously increased by doubling the work crew (p_k^i is constant) This accelerates the starting times for each task, while shortening completion times. Undoubtedly, all realligning techniques, like adding resources or changing working pace should be *considered carefully* by the planner. *Even though they may seem lurcative to reduce project duration, they strongly infuence in feasibility of the schedule, cash-flows and resources' exploitation!*

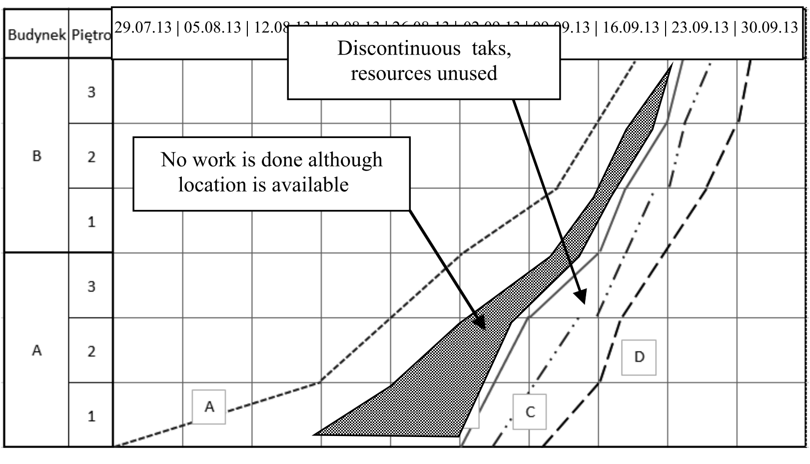

Fig. 4. An example flow-line chart before adjustment

The planner should also note that repetitive activities may bring about an improvement in labor efficiency. The straight-line power model of *crew learning* proposed by Arditi in 2001 [4] is thought to be the most reliable predictor of future performance. Therefore, the scheduler should consider establishing learning rates for each schedule task, using learning functions or production rate multipliers smaller than 1.0 in the early locations.

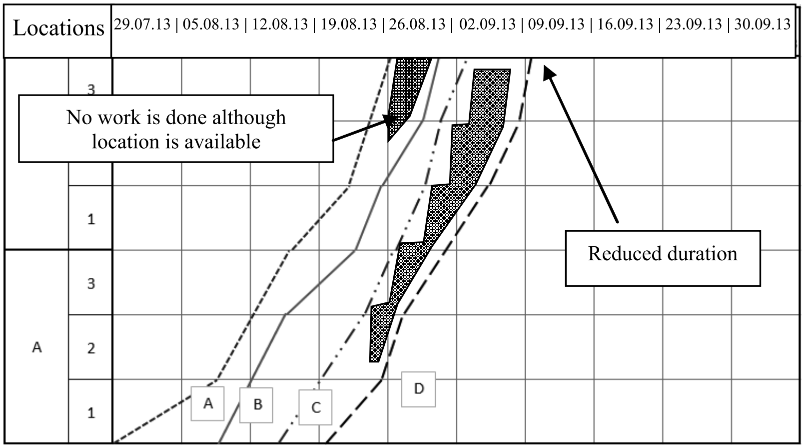

Fig. 5. An example flow-line chart after adjustment

3. Integrated planning system – general remarks, possible improvements. Conclusions

Current research on project management and automation focus on the tight integration of BIM tools, such as *Tekla*, *Revit*, *ArchiCad,* with applications useful for project management. The most powerful tool and virtual construction environment nowadays is *VicoSoftware* by Trimble LTD, which supports the planner with 3D virtual construction synchronization, estimating and scheduling data. Even though a 5D environment is available on the market, it needs further investigation and improvement, as it doesn't always work properly or effectively.

First to come is the automatic quantity take-off problem. Modern 4D or 5D CAD software with import construction components and extract quantities directly form a model created in an independent application. While BIM modeling is thought to be the best way to check the constructability of the structure and QTO, which seems to be the best way to eliminate negative aspects of the manual-based (human-based) measurement process, in order that there are no application gaps, which may have an impact on effective project planning.

Designer's not only make mistakes in the system, but application bugs may also affect the basic quantity take-off, particularly in scope of concrete and finishing works. Without an add-on on application, which is usually a separate software delivered by formwork supplier, it is not possible to generate formwork elements properly. Even if the BIM system creates formwork construction for basic elements like a beam or a slab, it is often incomplete (props, alignment couplers etc. are missing). Problems can also be a simplified definition of reinforcement, when the planner indicates only a reinforcement ratio, which doesn't always correspond to complexity or reinforcement alignment. Moreover, where elements intersect, removed quantities can be overestimated, which disturbs the bill of quantities and therefore total labor and material demand.

As one can see, BIM based on the quantity of 'take-off', potentially making it one of the most important applications of the BIM technique, however it is still not able to meet fully all user's needs.

The second issue, equally important to QTO, is labor demand estimation in the scope of repetitive works. Schedule control over workflow and works' efficiency often indicates schedule delays or acceleration, which may be caused by different factors. One of them is crew learning curve, which is why there is a benefit form the repetition of tasks, as discussed above. Apart from this, different completion times can also be derived from inaccurate unit labor demand estimations. This is why it is crucial to create a real-data dynamic database, consisting of real-life coefficients and unit labor demand values. Such a database should be combined with the whole planning system (as in Fig. 1) and the planner should have the possibility to not only to download the data, but also to upload his own records. The data put in by the planner, to be useful for other users, should provide detailed information on working conditions that may affect unit labor demand. These could be: weather conditions (depicted as favorable or unfavorable), crew's experience (crew highly, averagely or inexperienced), works mechanization and automation (high, average or none), construction's complexity (high or average), etc. The database won't work well without an intelligent database manager, which will classify the collected data. To solve the classification problem AdaBoost-based classifier ensembles are suggested, as they create a highly accurate and predictive rule, even if the training data set is of poor quality.

All these issues combined together with the LBS technique are believed to be a powerful tool for effective planning, schedule control and optimization. Therefore 5D logic needs further investigation in order to work properly and effectively.

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TECHNICAL TRANSACTIONS | **CZASOPISMO TECHNICZNE**
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USE OF THE KASS PROGRAM IN SCHEDULING

ZASTOSOWANIE PROGRAMU KOMPUTEROWEGO KASS W SZEREGOWANIU ZADAŃ

A b s t r a c t

This paper presents uses for the KASS (Krzeminski Algorithm Scheduling System) program in scheduling for construction projects. The program serves as a tool for scheduling for up to a maximum of 10 work crews at 13 work sites, and then applies a **complete overhaul** in simulation. This paper describes the first version of the program released in 2012, as well as the modified version introduced in 2013.

Keywords: scheduling, construction scheduling, flow shop models

S t r e s z c z e n i e

W artykule zaprezentowane zostaną możliwości zastosowania programu KASS (Krzeminski Algorithm Scheduling System) w szeregowaniu zadań dla celów budownictwa. Program służy do szeregowania pracy maksymalnie 10 zespołów roboczych na 13 działkach z zastosowaniem przegląd zupełnego lub na 50 działkach przy zastosowaniu symulacji. Pokazana zostanie pierwsza wersja programu z roku 2012 oraz modyfikacje, jakie zostały wprowadzone w roku 2013.

Słowa kluczowe: szeregowanie zadań, harmonogramowanie budowlane, modele przepływowe

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1. Introduction

The construction scheduling problem is particularly important when a task accomplishment process is being prepared. Scheduling is a fast-growing area of scientific research in construction production engineering [11]. Methods of artificial intelligence, such as genetic algorithms, ant colony optimization algorithms, simulated annealing, neural networks have all been applied as well as fuzzy logic techniques. Elements of fuzzy logic are now being widely used in order to determine time.

This paper investigates a flow-shop scheduling problem [9, 10], which consists of having to determine the optimum working sequence for crews (known in the KASS (Krzeminski Algorithm Scheduling System program as brigades) at work spaces. The model is based on assumptions necessary for performing a sequence of technological operations, which were determined in advance and cannot be changed. For certain reasons, each crew could only work at any selected work place once, swapping shifts with another crew at an exact time. In total there are three main types of processes, one type being homogenous and heterogeneous [12]. In all of them, the same technological activities are being performed. The only difference lays in time: in heterogeneous operations it does not change linearly with the change of the work space. This is why it is essential to use advanced optimization methods in order to avoid work stoppages and minimize work time.

Scheduling is an advanced area of scientific research [8]. There are numerous models for determining the right sequence for the work at work spaces. Nevertheless, one must observe that the construction industry is a branch with only a slight repeatability of projects. Taking that into consideration, we can claim that general models which have been elaborated from models prepared for industrial purposes are often inapplicable. This is why the author aims to devise a system, which will provide specific scheduling, for construction projects.

2. Assessment criteria in scheduling

This chapter presents a set of criteria which form the basis of the the KASS program, devised for flow-shop scheduling [4]. According to the author, thanks to these criteria, scheduling is in line with construction project characteristics.

The first criterion is to select the **Shortest work accomplishment time**, in other words the shortest scheduling duration/time [1, 2]. This criterion often appears in scheduling optimization tasks. It is particularly important for the construction industry, as it determines work/ task accomplishment times. If we want to find the shortest work/ task accomplishment time for the schedule, we need to use the following equation

$$T_{\min} = \min\left(T_{nm}^{k,1}, T_{nm}^{k,2}, \ldots, T_{nm}^{k,u}\right), \tag{1}$$

where

u – stands for consecutive variants of scheduling,

T_{nm}^{k} – accomplishment time last task in chosen scheduling.

The next and one of the most important assessments, is **Crew working continuity**. Every proprietor/owner is set on having a well-qualified and harmonious team. One element that helps to achieve this goal is to ensure that workers are paid properly and it should be underlined that salaries depend on crew efficiency. It is then possible to conclude that the working continuity is very much needed in order to have a good team, which also serves to acquire harmony.

Crew working continuity may be determined by choosing the solution which has the lowest value for work stoppages. In order to use crew optimization for chosen **i-** (known as a brigade), we may do the following equation:

$$CPB_{i,\min} = \min\left\{ \left(\sum_{j=1}^{m} T_{i,j}^{p} - T_{i,j-1}^{k} \right)^{(1)}, \left(\sum_{j=1}^{m} T_{i,j}^{p} - T_{i,j-1}^{k} \right)^{(2)}, \ldots, \left(\sum_{j=1}^{m} T_{i,j}^{p} - T_{i,j-1}^{k} \right)^{(u)} \right\} \quad (2)$$

where:

u – stands for consecutive variants of scheduling.

It is also possible to use optimization for minimal total work stoppage time of all working brigades $CPB_{\min}$. In order to do this, we may use the following equation:

$$CPB_{\min} = \min\left\{ \begin{array}{l} \left[\left(\sum_{j=1}^{m} T_{1,j}^{p} - T_{1,j-1}^{k} \right)^{(1)} + \left(\sum_{j=1}^{m} T_{2,j}^{p} - T_{2,j-1}^{k} \right)^{(1)} + \ldots + \left(\sum_{j=1}^{m} T_{i,j}^{p} - T_{i,j-1}^{k} \right)^{(1)} \right], \\ \left[\left(\sum_{j=1}^{m} T_{i,j}^{p} - T_{i,j-1}^{k} \right)^{(2)} + \left(\sum_{j=1}^{m} T_{i,j}^{p} - T_{i,j-1}^{k} \right)^{(2)} + \ldots + \left(\sum_{j=1}^{m} T_{i,j}^{p} - T_{i,j-1}^{k} \right)^{(2)} \right], \\ \left[\left(\sum_{j=1}^{m} T_{i,j}^{p} - T_{i,j-1}^{k} \right)^{(u)} + \left(\sum_{j=1}^{m} T_{i,j}^{p} - T_{i,j-1}^{k} \right)^{(u)} + \ldots + \left(\sum_{j=1}^{m} T_{i,j}^{p} - T_{i,j-1}^{k} \right)^{(u)} \right] \end{array} \right\} \quad (3)$$

where:

u – stands for consecutive variants of scheduling,
i – number of brigade,
j – number of consecutive workspaces.

The last criterion used in The KASS program is **Works Transition Cost** [7]. The cost consists in all kind of expenditure, not only the financial one.

Work accomplishment time may vary considerably at different work spaces. If this is the case, the scheduling model could provide an optimal sequence in relation to previously mentioned criterion, such as crew (brigade) work continuity. Nevertheless, this scheduling could be deprived of fluency in working crew transition (within workspace).

The aim of this scheduling criterion is to ensure the lowest Works transition cost [3]. To achieve that, it is necessary to form a series of cost matrices for each working crew (brigade) transition within each Works MKi and it needs to be done at the stage when the data is introduced. Matrices does not need to be symmetric, however, if crew transition is not problematic, there is no need to introduce any matrix. This is how a matrix of cost should be defined:

$$MK_i = \begin{bmatrix} 0 & k_{12} & \dots & k_{1j} \\ k_{21} & 0 & \dots & k_{2j} \\ \dots & \dots & 0 & \dots \\ k_{j1} & k_{j2} & \dots & 0 \end{bmatrix} \tag{4}$$

where:

i – stands for a number of brigade,

j – stands for a number of workspace.

When we obtain scheduling data which is consistent with the previously mentioned criteria, we can determine the working crew (brigade) KBi transition cost within a chosen work space. It is essential to choose the solution which has the lowest transition cost, according to the following equation:

$$KB_i = \min\left\{KB_i^{(1)}, KB_i^{(2)}, \dots, KB_i^{(u)},\right\} \tag{5}$$

where:

u – stands for consecutive variants of scheduling.

The above-mentioned criteria were used in the KASS v.1.0, as well as KASS v.2.0. The program has not been finished yet, which means that it does not include all of the possibilities described.

3. KASS v.1.0 program description

The KASS v.1.0 program was written in the Java programming environment. This is a program which does not require installation. It can be downloaded for free from the website www.ipb.edu.pl, in the Programs tab. The program has an interface in both Polish and English. The first version contains three criteria: Shortest work accomplishment time, Crew (brigade) working continuity and Works transition cost. It was possible to use the Shortest work accomplishment time or the Minimization of work stoppages as the main criterion, as well as the Works Transition Cost as an additional criterion. Optimization calculations are carried out using the complete overhaul. It is possible to use optimization for a maximum of 10 working crews (brigades) at 13 work spaces. The limit concerning workspace count results from current PC computing capabilities: 13 is currently the highest figure which permits a quick and efficient calculation. More information on the KASS v.1.0 program can be found on the website www.ipb.edu.pl [5, 6].

4. KASS v.2.0 program description

The KASS v.2.0 program was also written in the Java programming environment. It also has a bilingual interface, it does not require installation and it can be downloaded for free from the website www.ipb.edu.pl (This applies to both versions).

The second version of the program has a slightly different layout, but more important changes were also introduced. The program **uses** the complete overhaul, when no more than 13 work spaces are considered. If there are more work spaces, we apply a simulation. The program also provides a new criterion of optimization that takes into consideration chosen brigade's continuity of work.

To show how the program works, we will use the example of optimization for chosen task. Fig. 1 depicts the welcome window that appears after we start the program.

Fig. 1. The welcome window of the KASS v.2.0 program

After we press the button Next, we move to the next window and we need to choose workspace count (seven in this example), as well as working brigades count (two in this example).

Fig. 2. The configuration window of the KASS v.2.0 program

It is also necessary to choose an assessment criteria which will be taken into account during optimization calculations. It is possible to choose from one to four criteria (the shortest work accomplishment time, crew (brigade) working continuity counted for all crews, chosen crew (brigade) working continuity and the lowest transition cost within work spaces. In this example **shortest** work accomplishment time was chosen as the main criterion, continuity of crew (brigade) number 2 is the second criterion and the lowest transition cots the last criterion. The criteria sequence is important, as it sets its precedence. The first one will influence the most the results of optimization. The picture above depicts those criteria input window.

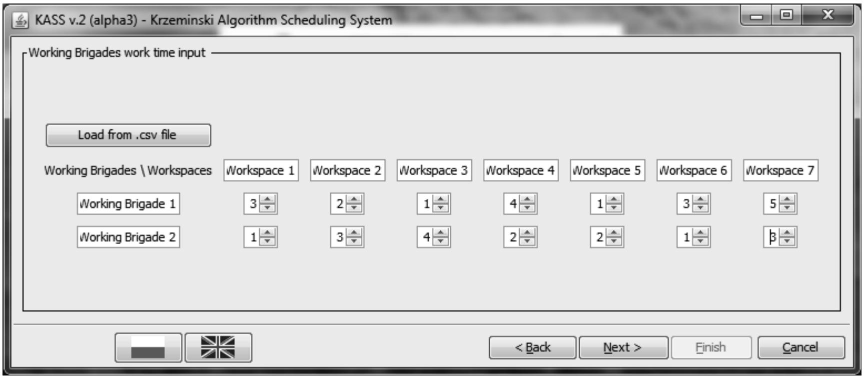

Fig. 3. The working brigades work time input window of the KASS v.2.0 program

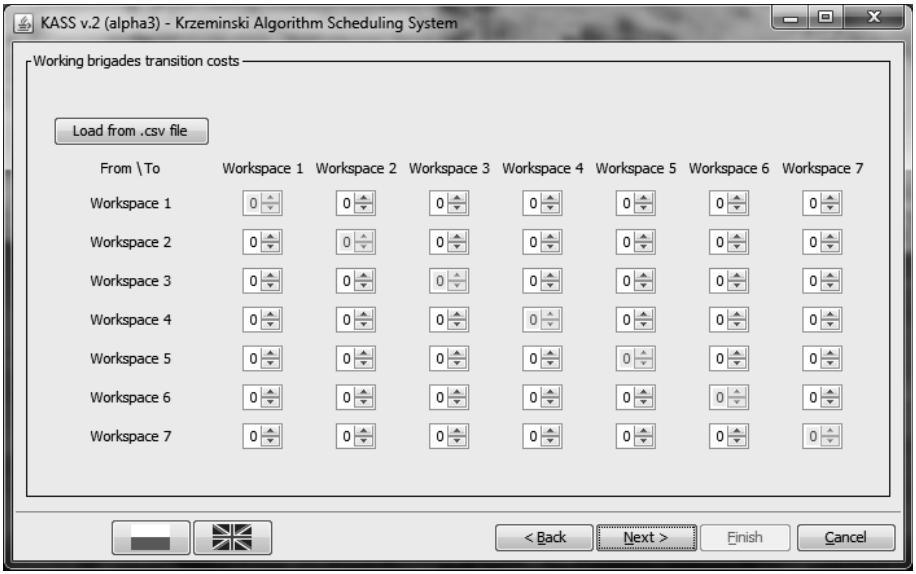

Fig. 4. The working crew (brigade) transition cost input window of the KASS v.2.0 program

After we press the button Next, we move to the working crew (brigade) work time input window. It is depicted in the Fig. 3.

The table in the Fig. 4 is a matrix of working crew (brigade) transition cost. As it was mentioned before, this matrix does not need to be symmetric. In this example, the value 0 was put in all of the fields intentionally.

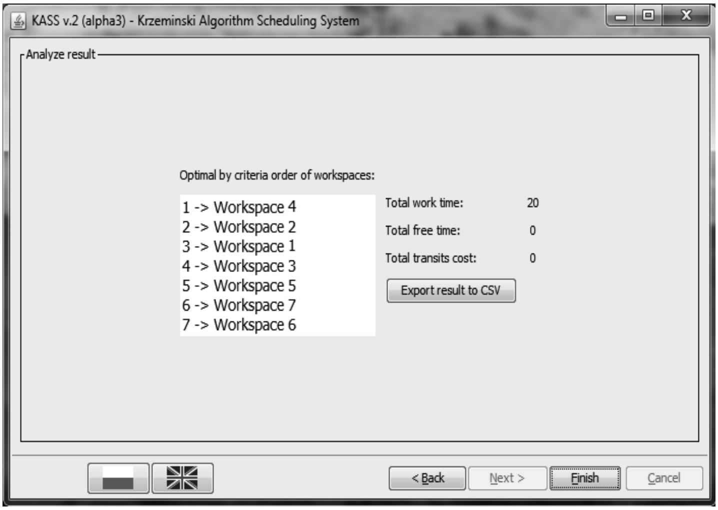

Fig. 5. The results window of the KASS v.2.0 program

Fig. 5 depicts the results. The window presents the right scheduling and it is also possible to read off data concerning total time, total crew (brigade) work stoppages, chosen crew (brigade) work stoppage and crew (brigade) transition cost.

It is also possible to save the results as *.csv files, which are readable in the Excel program among others. This is useful, because it enables the KASS v.2.0. users to work further in an easy and comfortable manner on data that were obtained

4. Conclusions

The program presented in this paper may be helpful for scheduling, when it comes to cases where there are a sequence of operations that repeat themselves at numerous work spaces.

The program allows for up to 13 work spaces using the complete overhaul application. In other scientific areas, thirteen would not be considered as a high number, however, in the construction industry this is a reasonable figure. Complete overhaul is the best optimization method. If this number were to increase, we would then apply a simulation.

The example shown in this paper proves that it pays to build this kind of program, as the results provided are better than the solution that can be obtained by using Johnson's algorithm. Time is always the same in both cases and equals 20, but when it comes to the KASS program, there are no work stoppages as a result.

The author plans to work further on the KAAS program and enlarge criteria and introduce heuristics, as well as more elaborate probabilistic versions.

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ANNA SOBOTKA, KAZIMIERZ LINCZOWSKI*

ANALYSIS OF LOGISTICS FOR CONSTRUCTION SITE SUPPLY WITH REINFORCING STEEL

ANALIZA LOGISTYKI ZAOPATRZENIA BUDOWY W STAL ZBROJENIOWĄ

Abstract

Owing to the numerous advantages of this technology, the continuous development of monolithic constructions have been made possible. The complexity of structures using this technology have been made possible thanks to the use of modern shuttering, the production of high quality concrete mixes carried out by professional concrete-mixing plants and efficient logistics supporting investment projects. The weakest element in organisation of these works is the supply of reinforcing steel, an expensive resource which is consumed in large quantities thus requiring extensive logistical planning. On the basis of their professional experience, the authors of this paper present their analysis of logistical models for supplying construction sites with reinforcing steel. Using the AHP method, they carry out a multi criteria evaluation of possible supply systems. Then, applying decision inventory theory models, they determine control quantities leading to logistic system optimisation according to the selected criteria.

Keywords: reinforcement steel, logistics of supplies, models, decisions

Streszczenie

Obserwowany jest ciągły rozwój budownictwa monolitycznego, dzięki licznym zaletom tej technologii. Poziom wykonawstwa obiektów w tej technologii jest wysoki dzięki dostępności nowoczesnych deskowań, wytwarzaniu mieszanek betonowych wysokiej jakości przez profesjonalne betonownie i sprawnej logistyce obsługującej inwestycje. Najsłabszym ogniwem organizacji tych robót jest zaopatrzenie w stal zbrojeniową, którą zużywa się w dużych ilościach i jest strategicznym oraz drogim zasobem. Autorzy na bazie swoich doświadczeń zawodowych prezentują w artykule analizę modeli logistyki zaopatrzenia budowy w stal zbrojeniową. Za pomocą metody AHP przeprowadzają ocenę wielokryterialną możliwych systemów zaopatrzenia. Następnie, wykorzystując modele decyzyjne teorii zapasów, określą wielkości sterujące, prowadzące do optymalizacji systemu logistycznego wg wybranych kryteriów.

Słowa kluczowe: stal zbrojeniowa, logistyka zaopatrzenia, modele, decyzje

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1. Introduction

The building of modern structures requires the delivery of considerable quantities of building products and other resources to construction site. Among other things, the logistics of supplies affects the prompt completion of construction works as well as the cost and quality of the project components, and in particular safety of workers. The various logistical methods, with particular reference to expensive materials ordered in large quantities, needs to be controlled effectively.

In this article, the authors discuss supplying reinforcing steel for the construction of apartment buildings. Steel being a basic material used for erecting buildings and volumetric structures have a key impact on the basic works planned in the critical path schedule, and thus on the completion date of the project. On the basis of their professional experience, the authors present their analysis of logistical models for supplying the construction site with reinforcing steel, proposing a systematic approach to the logistical process of steel supply to a construction site. In the first stage, it involves carrying out a multi criteria evaluation of possible supply systems using the AHP method [1, 7, 8, 10]. This method allows for the best logistical service type. Then, applying the decision model of inventory theory, they determine control quantities leading to a logistical optimisation system carried out according to the selected criteria. These are delivery dates and volumes coordinated with the construction works schedule. The results obtained provide the basis for making decisions, which allow for a reduction of logistic costs.

2. Organisation of logistics for construction site supply with reinforcing steel

In the case of buildings constructed using monolithic or improved conventional technology, the main aspects of supplying building products to the construction site are the limited supply of reinforcing steel or small-sized components (hollow bricks/blocks of different types). Due to the high diversity of hollow bricks and blocks, the authors renounce describing that resource as being available, proportionally cheap and easy to replace. Producing reinforced concrete elements on a construction site involves form work fitting using the wide range of systems offered by manufacturers, prior to commencement of works brought to the construction site. After the installation of the reinforcement in the shuttering, the concrete mix is poured, this usually being brought to site directly from a concrete-mixing plant and pumped into the form work. In the case of resources, the logistical issue first refers to the selection of a good manufacturer, who will guarantee good quality material, competitive prices, suitable payment conditions and efficient transportation, etc. The shuttering set required is delivered before the commencement of works, and the concrete mix is delivered via the *Just-in-time* system. Therefore, the only logistical benefit is to seek better solutions for the supply of reinforcing steel and in particular reduction of costs. Due to design diversity and required assortment of steel to be built into the structure and its current market cost, reinforcing steel is a material, which may affect the investment project's implementation not only from a logistical, but also financial point of view.

As regards organization, the most convenient solution for reinforcing steel deliveries could be to store complete or partial steel demand – in advance of one full constructional element on site – consuming the steel as required. However, this is economically unjustified, as this would mean the need to freeze company financial means. Figure 1 shows organisation of reinforcing steel deliveries to construction site at various conditions.

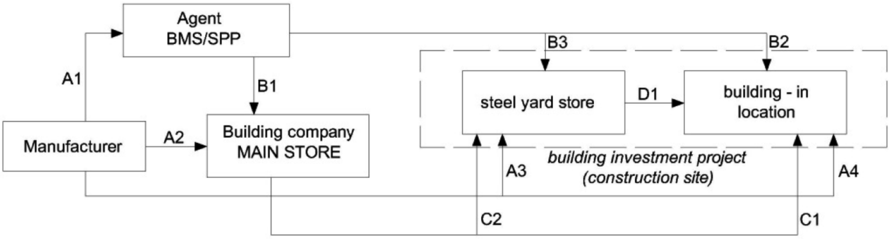

Fig. 1. Organisation of logistic chains for reinforcing steel deliveries to its building-in location

Chains starting with letter A indicate delivery of a specific assortment, amounting to a full transport of reinforcing steel (24 tons, transported units 12 metres in length). This amount constitutes the logistical minimum in order for a target buyer to get a competitive price from the manufacturer. Therefore, it is frequent building company practice to buy steel through agents (chains starting with letter B). Typical agents in reinforcing steel sales are building materials stores (BMS). The advantages resulting from shopping at BMS include:

1) possibility of satisfying diversified construction site demand for steel at advantageous conditions as regards prices, assortment and quantity – benefiting from scale (mass) effects of BMS purchases from manufacturer;
2) convenient delivery. The building company implements investment projects in various locations and at various distances from the steel manufacturer's plant. During logistical planning, the company possessing a contract with one or more BMS's agrees upon a delivered price to the specific construction site. As a result of this, the building company does not incur extra transportation costs (for orders covering steel delivery for the entire investment project);
3) limited storage. A specific amount of steel is delivered to the construction site, directly to the location of its incorporation into an erected structure (division of the whole order into parts satisfying logistic minimum of BMS). As a result of this, building company does not have to store material on site and therefore does not incur any extra costs. Storing steel on a construction site involves transportation and hoisting costs within construction site. In the case of steel characterised by disadvantageous dimensions for transportation (packaging in bundles, considerable weight of individual bundles)which is expensive because it requires hoisting crane or tower crane to be operated at builder's yard.

BMS's deliver primarily straight steel, and the proper shapes and lengths for building-in are to be prepared on construction site. In the case of complicated design solutions with unusual bending of reinforcing shapes and/or using diameters exceeding Ø16 (frequently Ø20, Ø32 or higher) the full working of straight steel on site is unprofitable, and sometimes impossible due to the limitations of mobile shears and mobile bending machines for steel. In these cases, the third option is to use the steel suppliers selection, that is the steel prefabrication plant (SPP). SPP performs work on large reinforcing steel diameters, including both the cutting and bending of elements/shapes (plants of this type are equipped with stationary machines allowing production of steel shapes of any diameter). Reinforcement made at SPP is characterised by good quality, accurate workmanship and repeatability of shapes, which are more difficult to obtain on a construction site due to: weather conditions, workers' fatigue, bending inaccuracy due to rushing (steel fixers' gangs are paid for built-in steel tonnage), low quality of manual bending machines (this is very important in production of e.g. stirrups), etc. Reinforcing steel supply from SPP increases reinforcement costs, but it speeds up the production process, reduces labour consumption and labour costs for steel building-in into the structure, and often turns out to be the only possibility of incorporating designed reinforcement into an erected structure. In the case of steel deliveries by SPP, financial and transport-related solutions are similar to those applied by BMS. A frequent practice of building companies is to buy steel from BMS and SPP, and at the same time from manufacturer (Fig. 1).

The practice shows that due to fluctuations in steel prices, building companies implementing many investment projects in a given accounting period purchase steel in higher quantities and deliver it to the main store. This requires possessing free funds and usually means freezing capital over a longer period. Capital freezing may be determined according to cost estimates, because when signing contracts, building companies estimate prices of steel at the moment of signing the contract. Storing the require volume of steel avoids any unpleasant surprises in form of a sudden increase in the price of steel, but also means lost benefits in case of drop in steel prices. When a building company decides to store reinforcing steel in its main store, it has an opportunity to replenish steel stocks at individual construction sites (C chains). D chain indicates in-house transportation within construction site area of spatial reinforcement components assembled in a steel yard.

In most cases reinforcing steel is stored in the form of straight steel. The storing of bent steel is limited exclusively to specific, planned investment project. Assortments of this type cannot be treated as a reserve or long-term investment.

3. The method used to support logistic decisions of reinforcement supply

The authors suggest a two-stage planning of logistic support for reinforcement works while building reinforced concrete structures using improved conventional methods at a construction site (involving selection of logistic chain type/delivery type), and determining the parameters of the logistical processes, that is first of all: delivery dates and optimal size of delivery batch due to the criterion of minimising costs of logistics (logistic processes/ support). The first stage involves an analysis of structure documentation and identification of external and internal logistic determinants, which directly affect the selection of the support model type using the AHP method [1, 7, 8, 10]. The second stage involves the acceptance of an appropriate model of inventory theory and determination of optimal logistic decision variables minimising logistic costs [4, 5, 6, 8].

3.1. The stage of selecting the type of logistic model for supply

The authors have carried out hierarchic analysis for reinforcing steel deliveries. Three models presenting the types of delivered assortments have been defined. Model I involves a delivery of steel from the manufacturer or through a building material store. Designed reinforcement is prepared for building-in at the construction site (one-type assortment: straight steel, transport length). Model II involves delivery of steel exclusively by the steel prefabrication plant – both steel shapes and straight steel of designed lengths. Model III involves delivery of steel from all suppliers depending on demand at the construction site or steel availability from individual suppliers.

The following characteristics of the first and second degree (Table 1) have been used for the purposes of evaluating the models above by way of the AHP multi criteria analysis. In order to carry out multi criteria analysis, the authors assumed the scale of comparative rating from 1 – for equivalent characteristics to 5 – for the most important characteristics. Since computational algorithms in the AHP method are presented in literature on the subject [1, 7, 8, 10], the authors show computed weights for first degree characteristics in Table 1.

Table 1

Comparison of computed values – characteristics of reinforcing steel delivery models

Model	Advancement of works 0.35*		Delivery type 0.13*			Payment 0.45*		Supplier 0.07*		Rating
	Quality 0.33**	Efficiency 0.67**	All 0.11**	In stages 0.26**	In stages with reserve 0.63**	Purchase costs 0.25**	Payment date 0.75**	Manufacturer 0.33**	Agent 0.67**	
I	0.10	0.11	0.10	0.10	0.11	0.54	0.33	0.60	0.14	0.24
II	0.62	0.58	0.67	0.62	0.58	0.16	0.33	0.20	0.43	0.17
III	0.28	0.31	0.23	0.28	0.31	0.30	0.33	0.20	0.43	0.28

* weights of the first degree characteristics, ** weights of the second degree characteristics

According to completed multi criteria analysis, the most advantageous model of reinforcing steel deliveries is model III (rating 0.28) – mixed assortment: straight steel and prefabricated steel, any supplier.

It should be emphasised that the final result of the analysis above was dependent on the planner's assumptions regarding phenomena, which affects the values of the characteristics of the models considered in a given time and for given building and market conditions.

3.2. Optimising calculation – selection of decision variables

Optimisation of logistic systems (support) for procurement of building undertakings is a complicated task. A building investment project is a special product, and its progress is not fully predictable (in particular regarding earth and foundation works). Model selection, applications for optimising calculations and the implementation of results is not an easy or conventional task.

The literature presents two main groups of stock control models: deterministic and probabilistic. Deterministic models include: the graphical method for determining stock volume, the analytical-graphical method for determining stock volume, taking discounts into account, the optimal order size model, the no-stock model, the dynamic stock control model, the *Just – in – time* (JIT) system, etc. Probabilistic models include: the buffer stock model, the cyclic stock inspection model, the central store simulation model for determining stock volume with two unknowns, the simulation model for determining stock volume with three unknowns, the no-stock model with a known probability, the probabilistic dynamic stock control model and the system of complementary orders, etc.

Not all stock control models and methods can be used in the building industry. According to [4, 5] and experience of authors the most appropriate options are: the graphical method for determining stock volume, the analytical-graphical method for determining stock volume, the buffer stock model, and simulation models for determining stock volume with two and with three unknowns.

According to the authors, the most advantageous stock control model is the deterministic JIT system (no stock, perfect synchronisation of works with deliveries, etc.). Unfortunately, in practice building companies are unable to satisfy all of the objectives of the mentioned system. Delivering concrete mix in the JIT system does not provide a positive results in the case of all resources needed to complete building undertaking.

Reinforcing steel is one of the resources, which fail to satisfy JIT system objectives. It should be noted that even if we take the selected multi criteria analysis, the most elastic model of reinforcing steel deliveries (model III) – supplied reinforcement requires final working before being incorporated in the structure (this will primarily involve construction of spatial elements including beams, poles, etc.).

In order to illustrate an application of logistic support planning that minimises the total logistical costs for steel supply, it is assumed that in the construction of certain multi-storey apartment building, built using improved conventional technology, logistic support will be provided according to model II. Due to various (including practical) reasons, reinforcing

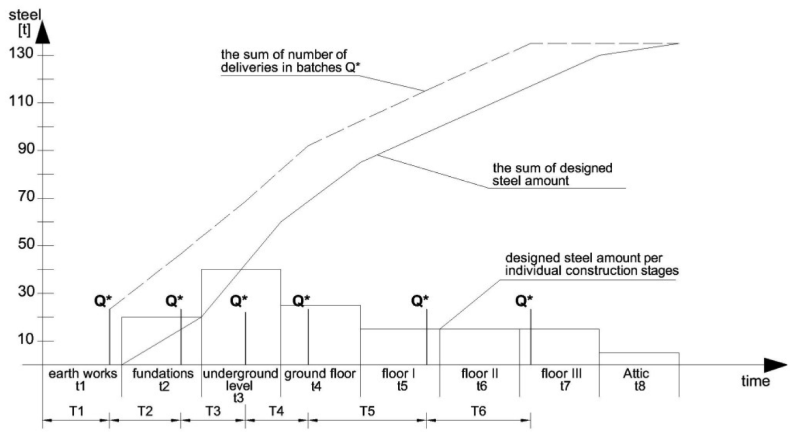

Fig. 2. Diagram showing steel demand for a building of improved conventional structure with trajectories of calculated material deliveries, Ti – intervals between deliveries, ti – reinforcement making durations at individual construction stages (Own study)

steel will be delivered by only one supplier (SPP) selected from among many others, e.g. on the basis of computations carried out using a transportation algorithm.

The formula defining optimal delivery volume at lowest possible logistic costs Q^* (*EOQ – Economic Order Quantity*) [8] is used to determine control variables for supply logistics management. Using this formula requires taking the following assumptions into account: a single product is ordered (one product type), the demand size (consumption, demand) is constant and known, orders are completed in a stable way (that is delivery completion time is constant), products are ordered and delivered in specific batches, delivery sizes can be characterised as optimal from a cost minimisation point of view and the cost structure is as follows: constant commodity unit cost, stock keeping cost linearly depends on an average stock level, the cost of making orders is constant in the case of each ordered batch, independently of its size.

Knowing the total steel consumption, it is possible to estimate Q^*, assuming certain level of costs involved in stock keeping and order handling according to the following formula:

$$Q^* = \sqrt{\frac{2 \cdot D \cdot k_s}{p \cdot c}}, \; n = \frac{D}{Q^*} \tag{1}$$

where:

- Q^* – the optimal delivery size [commodity unit],
- n – required number of deliveries to the construction site [pcs.],
- D – the total demand volume: 135 [t],
- k_s – unit order handling costs 600 [PLN/order],
- p – annual, percent rate of stock keeping costs [%/year] (stock keeping for one year) 15[%],
- c – unit cost of gathered stock 2000 [PLN/t].

According to the formula above, the optimal delivery size is Q^* = 23,24 [t]. Maximum load size in a standard mean of road transport (set consisting of truck and semitrailer) is 24 tons. The required number of deliveries (rounded to Q^* = 23 [t]) n = 5.81 [pcs.] is 6 (taking assembly bars into account). Due to the higher demand for steel during building raw state construction than will be used in successive storeys, it is planned to depart from deliveries at identical time intervals and reduce delivery cycle at initial period of construction works. Figure 2 shows distribution of deliveries to ensure designed steel volume and safe reserve.

Total logistic costs for supplying construction site with reinforcing steel in the discussed example can be estimated as follows [8]:

$$K_l = K_S + K_O + K_m = k_S \cdot n + c \cdot D + p \cdot c \cdot \frac{Q^*}{2} \tag{2}$$

where:

- K_S – order handling costs (purchase, including transportation),
- K_o – costs of freezing circulating means (capital),
- K_m – stock keeping costs (taking into account Q^* – optimal delivery batch, also called economic); other symbols as in formulas (1).

Minimum logistic costs planned according to the above calculations and assumptions have reached PLN 277,086 net.

4. Conclusions

Undoubtedly, the best steel delivery method from a theoretical point of view is model III – involving the supply of straight steel and prefabricated steel. It requires knowledge of sophisticated optimisation methods. Although owing to the computerisation it is possible to include the dynamics of market conditions and construction site specifics. There is some "inertia" in the implementation of results, caused for instance by former commitments between suppliers and consumers, it is not always possible to use it in practice. If steel demand per investment project allows for the selection of two suppliers in parallel, it is an advantageous negotiation argument for settling the price and ensuring continuity of deliveries to the construction site – in particular during a peak of orders for building materials during the year, which falls at the end of summer and the beginning of autumn.

Due to the nature and practice (supply logistics) of work on construction sites, the most suitable for use are: the graphical method for determining stock volume, the analytical-graphical method for determining stock volume, the buffer stock model and simulation models for determining stock volume with two and three unknowns. The graphical-analytical method is used most frequently by contractors, primarily because it is easy and clear. It gives results, which may be read directly from diagrams. These results allow for prompt analysis, owing to which we may quickly determine selected variables and modify the stock control model (in spite of the fact that obtained results do not satisfy all optimisation criteria). Moreover, data for calculations concerning the analysis are generated by professional applications for construction work scheduling, universally used in investment project implementation management. This gives us an opportunity to monitor logistic costs systematically during the construction, allows also for the planning and quick adjustment of objectives to dynamically changing progress in construction works.

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TIME AND COSTS ANALYSIS OF PRODUCTION LOSS IN BONDED TECHNOLOGICAL WORKS SERIES

ANALIZA CZASOWO-KOSZTOWA STRAT PRODUKCYJNYCH W WIĄZANYM CIĄGU TECHNOLOGICZNYM ROBÓT

A b s t r a c t

Production downtime results from the technological regime of production processes, established in production diagrams as network nodes. Their direct cause in the lack of harmonization between working teams, diversity of performance of hardware units – working in mixed systems, and different labor construction processes, performed on the same working plots. Time and costs analysis lies in optimizing the downtime of production resources using the "by-pass" production, which allows production labor (*R*) and hardware measures (S) for the implementation of part of the process. This tool is defined in network nodes, slowing down the production and binding the run of the production front with a two criteria network plan: technologically and organizationally. The technique is based on an algorithm of the limitations of renewable resources of means of production, which assumes the full availability of construction materials, available from storage sites. The paper presents an analysis of fixed and variable investments costs in terms of compensating for downtime.

Keywords: monitoring costs, schedule, production loss, by-pass

S t r e s z c z e n i e

Przestoje produkcyjne wynikają z reżimu technologicznego procesów produkcyjnych, utrwalonych w diagramach produkcyjnych w postaci węzłów sieciowych. Ich bezpośrednią przyczyną jest brak harmonizacji w pracy brygad roboczych, zróżnicowanie wydajności jednostek sprzętowych – pracujących w mieszanych układach – oraz odmienne pracochłonności procesów budowlanych, wykonywanych na tych samych działkach roboczych. Próba analizy czasowo-kosztowej polega na optymalizacji przestojów środków produkcji przy zastosowaniu *by-passu* produkcyjnego, który zezwala robociźnie produkcyjnej (*R*) i środkom sprzętowym (*S*) na realizację części procesu. Narzędzie definiowane jest w węzłach sieciowych, wyhamowujących produkcję, wiążących bieg frontu produkcyjnego przez plan sieciowy dwukryterialnie: technologicznie i organizacyjnie. Technika bazuje na algorytmie ograniczoności odnawialnych zasobów środków produkcji. Zakłada pełną dostępność surowców i materiałów budowlanych, dostępnych z placów składowych. W pracy przedstawiono analizę kosztów stałych i zmiennych inwestycji, pod kątem podatności na wyrównanie przestojów.

Słowa kluczowe: monitoring kosztów, harmonogram, straty produkcji, by-pass

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1. Introduction

Costs control during implementation helps to maintain the required number of intervals, as well as material and temporal parameters of the investment [4]. The main object of control is the investment budget, revised at certain intervals (e.g. monthly) or continuously.

Problems associated with uniform working methods were initiated in the USA, where the case of repeatable project planning methods where based on the equilibrium line method, described as LOB (*Line of Balance*), LSM (*Linear Scheduling Method*), VPM (*Vertical Production Method*) [3].

A uniform work order on the working fronts by a site foreman provides a sense of organizational control. However, if fronts working differ due to an assortment scope of work, then such a system can be unfavorable for harmonization. It is not difficult to imagine a situation in which one working front is waiting for the release of the next (in the current schedule), although the team could continue on an other working front, the team (Known as a brigade) may be planned for a different task following on from the one they are working on [8].

Here a tool named the production "by-pass" may be useful as it can help to minimize downtime by allowing for renewable production resources (*R* and *S*) in order to proceed with selected working operations [11].

In the control of construction processes, operating within production systems, the philosophy of control [2], which is the permanent supervision and analysis of activities from the point of view of the objectives, and possibly the earliest introduction of control measures. Production losses, resulting from downtime are an inherent and undesirable element of any investment cycle.

They may be caused by random chance, due to the impact of external factors (weather, punctuality of suppliers and subcontractors etc.) which do not depend directly on the contractor.

These restrictions cannot be controlled in the preparation of the overall construction schedule. This can be done at the end (*ex post*) of consecutive stages of production, by analyzing whether there are retained [7].

Technological and organizational factors, involving the lack of adequate monitoring processes and response to the increasing deviation of the planned costs to those actually incurred also play a part.

An adopted costs plan, used as reference for the monitoring and control of costs throughout the duration of the investment cycle is shown in [12].

Modeling of works technology, the construction of models describing the structure and parameters of the technical, technological, organizational and economic resources means distinction and description of resources, dictating the analyzed processes timing and construction costs are shown in [6].

Coupling successive working fronts bind subsequent works of all kinds, inside each partial complex, specifying the degree of continuity of occupation of partial fronts [9]. If, on the front after the preceding job immediately begins the next one (there are no down times at the front), coupling is equal zero. Relations between fronts then shorten the total time of works execution.

Coupling occurring between working parcels, which are elements of the examined system [5], may constitute a direct relationship between successive bands of related processes or effect the activity within technological process, supported by common renewable resources.

In any case they will create cost-intensive down times – caused by variable labor-intensive processes on the plots and different founds circulation.

2. Subject matter and methodology of research

The subject of this research is the search for wasted production times, irretrievably lost in the organizational division on the verge of separation: *i* process/*j* plot ($I = l, \ldots, m; j = l, \ldots, n$) – by the limitations of the schedule.

Test methods based on predetermined objective functions define a time (workload) and costs (financial effort) of the analyzed process and the relocation of production means from its predecessors (i–1) to the successors (i+1) of the examined *i* process and to the numerically corresponding working plots.

3. The results of time and costs analysis

3.1. The matrix of the bound technological sequence

The choice of technological sequence schedule is determined by the links between labor and equipment as well as between successive building processes (i), supported by the same means of production.

Production in the range of reinforced concrete monolithic constructions binds ranges of reinforcement works and carpentry-concrete works. Constructing concrete sleepers for foundations (with staking) is made by carpenters and concrete workers (A) – for the next step these teams perform the so called opening and routing of form work for the sleepers is carried out.

Teams of steel fixers (B) arrange and bind grid/reinforcement baskets with spacers; followed by the installation of starters – reinforcement grids for fixing column and wall foundations. Carpenters (A) then close and fill concrete into these foundations: by this time at a square near the facility cutting and bending reinforcing steel for walls and columns is taking place (brigade B). After the removal of the form work by foundation teams from (A) walls and columns – after the installation of reinforcements (B) closure and concreting the components (A). Relationships that exist between these processes, takes the degree of division of an object on working plots and their workload, expressed with time and realization costs into account.

When analyzing the time-cost *m* of construction processes, implemented on *n* working plots through two ranges of renewable resources (A, B), the matrix of the bound technological sequence is:

$$C_{ij} = \begin{bmatrix} c_{11}^{A} & c_{12}^{A} & \ldots & c_{1j}^{A} & \ldots & c_{1n}^{A} \\ c_{21}^{B} & c_{22}^{B} & \ldots & c_{2j}^{B} & \ldots & c_{2n}^{B} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ c_{i1}^{A} & c_{i2}^{A} & \ldots & c_{ij}^{A} & \ldots & c_{in}^{A} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ c_{m1}^{B} & c_{m2}^{B} & \ldots & c_{mj}^{B} & \ldots & c_{mn}^{B} \end{bmatrix}_{mxn} \qquad (1)$$

where:

$c_{ij}^{A/B}$ – generalized matrix component, which expresses the time of production measures (*A/B*), performing the *i* construction process (*I* = 1, …, *m*) on *j* working plot (*j* = 1, …, *n*) of the construction [r–g/m–g].

3.2. The definition of the objective function

The purpose of the issue consists of minimizing downtime in production labor (R) and equipment (S) is used to define interruptions at work (T_{ij}), resulting from the need to maintain the technological regime and organizational disruptions, while transferring the means of production on these front works (*i–j*) which is the continuation of production.

If a x_{ij} (*I* = 1, 2, …, *m*; *j* = 1, 2, …, *n*) will be marked with a decision variable, defining a change of allocation of means of production of the *j* working plot and the *i* process for the future process *i+p* (*p* = 1, …, *m*–1), carried out on any successor plot *j+q* (*q* = 1, …, *n*–1) and by the k_{ij} corresponding to time production costs, the above problem of reclassification of renewable resources can be expressed as a function of the production purpose, minimizing production downtime:

$$\min(z) = \sum_{i=1}^{m}\sum_{j=1}^{n} k_{ij} \cdot x_{ij} \tag{2}$$

where:

k_{ij} – production cost in relation to process *i* on *j* working plot,

x_{ij} – decision variable (binary), making the reclassification of means of production, this problem has the following constrains:

1)
$$x_{ij} = \begin{cases} 1 \\ or \\ 0 \end{cases} \tag{3}$$

2)
$$k_{ij}^{'} \le \sum_{i=1}^{m}\sum_{j=1}^{n} k_{ij} \cdot x_{ij} \tag{4}$$

3)
$$p:(i,i+1), \quad q:(j,j+1) \tag{5}$$

4)
$$x_{ij} \ne 0 \rightarrow y(T)_{i+p,j+q}^{A,\ldots,B} : \sum_{p=1}^{m-1}\sum_{q=1}^{n-1} c_{i+p,j+q} \tag{6}$$

where:

k'_{ij} – production costs (*Ks*+*Kz*), reduced relative to baseline,

p, *q* – measures of the displacements of means of production within rows (processes) and columns (working plots) within the matrix of the bound technological sequence,

$y_{i+p,j+q}^{A,\ldots,B}$ – vector expressing displacement (*p*, *q*) means of production (*A* or *B*) – numerically about the process (*i+p*) and about the working plot (*j+q*).

The constrains of the objective function is the binary nature of the decision variable (3).

The resulting value of production costs of production processes (4) can't be higher than the planned costs – after the application of the algorithm. Measures of displacement of production means (5) define the displacements vector (y) held in the working direction of the successor of the analyzed process: they cannot be retroactive – as a result of the technological regime of works. Nonzero value of the decision variable (6) assigns the vector moving the means of production to the first construction process, on which the continuation of a construction working plot is possible during the term of its predecessor.

3.3. Time-cost matrix with movements of means of production

The adopted model of tasks allows for a flexible approach to the schedule optimization problem, by controlling the allocation of renewable resources.

The recognition of time and costs analysis comes down to assigning values to the planned production costs of construction processes schedule, taking their price setting components (R, M, S) and markups on the costs into account(Kp, Kz, Z).

After extracting those values from the offer cost estimate the matrix takes the form:

$$C(k)_{ij} = \begin{bmatrix} c(k)_{11}^{A} & c(k)_{12}^{A} & \dots & c(k)_{1j}^{A} & \dots & c(k)_{1n}^{A} \\ c(k)_{21}^{B} & c(k)_{22}^{B} & \dots & c(k)_{2j}^{B} & \dots & c(k)_{2n}^{B} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ c(k)_{i1}^{A} & c(k)_{i2}^{A} & \dots & c(k)_{ij}^{A} & \dots & c(k)_{in}^{A} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ c(k)_{m1}^{B} & c(k)_{m2}^{B} & \dots & c(k)_{mj}^{B} & \dots & c(k)_{mn}^{B} \end{bmatrix}_{m \times n} \tag{7}$$

where:

$c_{ij}(k)^{A/B}$ – generalized matrix component, which expresses the time of production (A/B), and the corresponding production costs (k) ($I = 1, \dots, m; j = 1, \dots, n$).

4. Usage in engineering

In order to illustrate the assumptions above, time-cost analysis were adopted as a temporary coupling of two work fronts, on which carpentry and reinforcement works are carried out. The technological sequence refers to the process of implementation of a monolithic slab made of reinforced concrete above the ground floor of the museum building, resting on monolithic reinforced concrete columns.

In the process presented, eight working operations were isolated (rows of the matrix) performed on four plots (columns).The values of the duration of operations were recorded in service hours (r–g). due to the costs (k), describing the fix and variable costs, the components are stored in the value of 1/1000 (PLN). The time-cost matrix, isolated from the general construction schedule (*c*) and offer cost estimate (*k*) takes the form:

$$C(k)_{ij} = \begin{bmatrix} 6(0,5)^A & 6(0,5)^A & 6(0,5)^A & 6(0,5)^A \\ 2(0,3)^B & 2(0,3)^B & 2(0,3)^B & 2(0,3)^B \\ 1(0,5)^A & 1(0,5)^A & 1(0,5)^A & 1(0,5)^A \\ 8(0,9)^A & 6(0,7)^A & 5(0,6)^A & 8(0,9)^A \\ 4(2,7)^B & 3(2,5)^B & 2(2,2)^B & 4(2,7)^B \\ 1(0,3)^A & 1(0,3)^A & 1(0,3)^A & 1(0,3)^A \\ 1(3,5)^A & 1(3,2)^A & 1(3,1)^A & 1(3,6)^A \\ 2(0,3)^B & 2(0,3)^B & 2(0,3)^B & 2(0,3)^B \end{bmatrix}_{8\times 4} \quad (8)$$

Working on plots, teams of carpenters (*A*) construct formwork for columns (line 1), concrete columns (line 3), the floor slab formwork (line 4), stamping of the floor (line 6) and its filling with concrete (line 7).

Teams of steel fixers work on the reinforcements of columns (line 2) and the reinforcement of the floor stab (line 5). For the analysis of one working plot (e.g. column number 1 of the matrix), with the method of future embodiment, the total duration of the process on the plot is: 6 + 2 + 1 + 8 + 4 + 1 + 1 + 2 = 25 r–g, with the total production cost (*Ks+Kz*) at 8700 PLN.

Differences in the cost of production on the plots, with identical labor needs, are due to the participation of material costs of the operation: lack of material component while stamping the floor (line 6) is characterized by costs several times lower in relation to concreting of the floor stab (line 7) – at the same time value.

The role of the "by-pass" is to streamline the production downtimes, generated when changing the assortment of means of production (labor), serving the analyzed construction process. These downtimes are formed in the matrix of bound technological sequence between the lines 1 – 2, 2 – 3, 4 – 5, 5 – 6, 7 – 8 – which is where one working team (brigade) – alternating between *A/B* – must make the working front available for the second team.

Waiting time – in the classical sense of the schedule – is lost time. The "by-pass" tool allows for both means of production realization as well as progression of some of the working activities during waiting time – while retaining the technological regime – in the course of their standstill, which – from a cost point of view – which is sometimes lost irrevocably.

The process of improved continuity is shown by the time-cost matrix (9). After the concrete column reinforcement baskets are completed (line 2), steel fixers (*B*) working on reinforcement of the floor stab (line 5) – the analysis of plot 1 – occurs after 9 r–g (sum of lines 3+4). At this time, minimizing the time buffer, created by waiting for the continuation of the process, team (brigade (*B*) proceeds with the pre fabrications of reinforcement of the stab: cutting and bending of steel, stirrup ruff ribs, (according to expenditures: 50% of labor need).

$$C(k)_{ij} = \begin{bmatrix} 6(0,5)^A & 6(0,5)^A & 6(0,5)^A & 6(0,5)^A \\ 2(0,3)^B & 2(0,3)^B & 2(0,3)^B & 2(0,3)^B \\ 1(0,5)^A & 1(0,5)^A & 1(0,5)^A & 1(0,5)^A \\ 8(0,9)^A & 6(0,7)^A & 5(0,6)^A & 8(0,9)^A \\ \overline{2}(\overline{1,4})^B & \overline{1,5}(\overline{1,3})^B & \overline{1}(\overline{1,1})^B & \overline{2}(\overline{1,4})^B \\ \overline{0}(\overline{0,0})^A & \overline{0}(\overline{0,0})^A & \overline{0}(\overline{0,0})^A & \overline{0}(\overline{0,0})^A \\ 1(3,5)^A & 1(3,2)^A & 1(3,1)^A & 1(3,6)^A \\ \overline{0,5}(\overline{0,1})^B & \overline{0,5}(\overline{0,1})^B & \overline{0,5}(\overline{0,3})^B & \overline{0,5}(\overline{0,1})^B \end{bmatrix}_{8\times 4} \qquad (9)$$

Management of production downtime – which in part resulting from the technological regime – will reduce, in a measurable way, the duration of line 5 of the matrix by half.

Similarly in case of team (brigade) changes (from A to B) in lines 5–6 of the matrix work sequence. Stamping of ceiling formwork is an operation which does not require the expectations of means of production at the end of the reinforcement of reinforced concrete elements. And here the "by-pass" prevents the downtime of teams (brigades) (A), eliminating downtime completely and allowing the carpenters to continue working.

The duration of the operation in line 6 is therefore zero, fits entirely into the time duration of its predecessor – the operation in line 5. Hence the costs of these activities, also paid for while at a standstill – regarding the renewable B resources (R and S) – are zero.

The standstill of steel fixers (line 5–8) will be used on another prefabricationof reinforcement for separate concrete structures: columns and sub strings of the first floor.

The installation of finished baskets and figures in accordance with factual inputs (R, M, S) requires 25% of time and 33% of costs of production of the starting expenditures: assuming that those activities will be carried out using the "by-pass" technique, while awaiting measures which will make the work front available again.

5. Conclusions

The analysis of time and costs of production downtime in the matrix of the bound technological sequence, using a production "by-pass" shows profits.

The variable costs of the process (*Kz*), with a constant composition of the brigades and production volume, remain on the initial level.

The reduction of fixed production costs (*Ks*), resulting from shortening the construction process (the "by-passed" process: 6 + 2 + 1 + 8 + 2 + 1 + 0 + 0,5 = 20,5 r–g) result from the implementation of selected, technologically possible, work operations, forming schedule activities when teams (brigades) come to a standstill – waiting the work front to become available. The representation of production downtime in network diagrams are nodes, culminating in production downtime and decelerating the manufacturing process.

The analyzed technological and organizational indifference s in relation to the predecessor – the successor can alternate between two or more of the means of production, pursuing a related technological sequence of the construction process. They can also exist in the global resource allocation analysis, both between indirect as well as direct predecessors and successors in the investment cycle.

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ASSIGNMENT PROBLEM AND ITS EXTENSIONS FOR CONSTRUCTION PROJECT SCHEDULING

ZAGADNIENIE PRZYDZIAŁU I JEGO MODYFIKACJE W HARMONOGRAMOWANIU PROCESÓW BUDOWLANYCH

A b s t r a c t

The assignment problem consists of allocating renewable resources (construction equipment, crews, or contractors) of limited availability to a set of activities. The classical model for this problem minimizes the total time or cost of completing all activities with the assumption that each activity is assigned to one particular resource. This paper systematizes and describes extensions of these assumptions, considering the effects of task sequence: parallel, serial and hybrid (modeled by means of network methods). This study proposes algorithms for the solution of presented models, which can be used in construction project scheduling.

Keywords: assignment problem, project scheduling, mathematical modeling, renewable resources, bottleneck assignment problem

S t r e s z c z e n i e

W zagadnieniu przydziału (znanym również w literaturze pod nazwą zagadnienia rozmieszczenia) rozważa się problem alokacji ograniczonej liczby zasobów odnawialnych (maszyn, brygad, wykonawców) do realizacji zbioru zadań. W klasycznym modelu tego problemu jest minimalizowany łączny czas lub koszt wykonania wszystkich zadań przy założeniu, że każda jednostka organizacyjna jest przydzielona do realizacji innego procesu. W artykule przedstawiono usystematyzowanie i modyfikacje tych założeń z uwzględnieniem różnej kolejności realizacji procesów: równoczesnej, kolejnej i mieszanej (modelowanej za pomocą metod sieciowych). Zaproponowano algorytmy rozwiązania opracowanych modeli, które mogą być stosowane w harmonogramowaniu procesów budowlanych.

Słowa kluczowe: zagadnienie przydziału, harmonogramowanie, modelowanie matematyczne, zasoby odnawialne, metoda minimaksowa

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1. Introduction

Assignment problems (selection and allocation of resources) are one of the primary task in construction process harmonization [9]. In its classical formulation n teams (crews, sets of construction plant, contractors) are assigned to n activities, in order to minimize the total time or cost of completing all of them. Arrangement of these activities depends on technological and organizational requirements. These requirements concurrently affect the allocation constraints, such as assigning only one job to each crew. With respect to technological constraints, options for conducting construction processes in parallel, in series, or in a hybrid way may exist (Fig. 1).

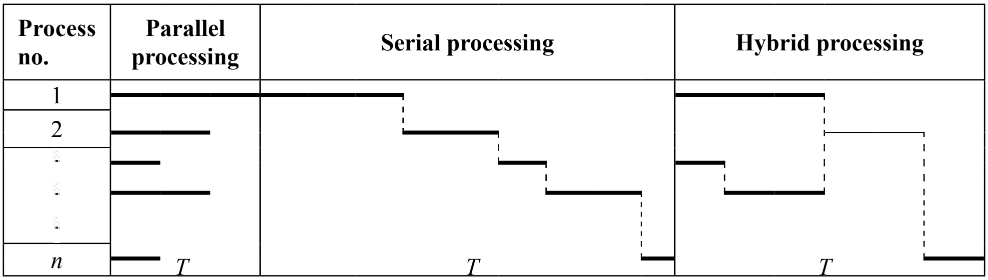

Fig. 1. Comparisons of different processing options in processes scheduling

Parallel processing consists of the simultaneous execution of activities by different resources in separate building units (work zones). The greatest advantage of this technique is the shortest project time span T – when compared with other approaches. The drawbacks of the parallel technique are: the lack of teams' work continuity and unleveled daily demand for building materials or plant.

Serial processing consists of performing a sequence of processes in one work zone. The advantage of this method is the lowest maximum level of daily employment of renewable resources and daily usage for building materials. Each activity may be realized by a different crew, but the total duration is incommensurately long. Another disadvantage, similar to the parallel technique is discontinuity of the team's work and unleveled daily consumption of resources.

Hybrid processing is a combination the two previous approaches. The precedence constraints, modeled by means of network techniques, enable serial processing of some activities (on the same network path) and, simultaneously, concurrent processing of other jobs on parallel paths. The two optimization approaches are used for resource management in project networks: allocation of limited resources (in order to minimize the project makespan) and leveling resource requirements profile (in order to improve economic efficiency).

This study considers different processing options for assignment problem formulation. It has been assumed that an activity requires one resource type for its execution (crew, contractor), and the resource can perform one activity at a time. In the case of parallel processing, each activity has to be carried out by a different crew. With serial processing, each activity can, but does not have to be conducted by a different crew. Thus, in the case of hybrid processing, parallel activities have to be entrusted to different crews, and activities scheduled in sequence can but do not have to be carried out by different crews. A discrete time/cost/resource function implies the representation of an activity in different modes of operation. For each activity i (construction process), a set of modes of execution is defined. Each mode, is described by the following parameters: $t_{ij} \in N$ – duration of the activity *i* realized by crew *j* and $k_{ij} \in R^+$ – cost of the activity *i* realized by crew *j*. The problem consists of choosing the optimal process modes in order to minimize the project duration or cost. Binary linear programs are developed to model the assignment problem for different processing options and recommended approach solutions are presented.

2. Assignment problem formulation for parallel processing

The classical assignment problem was formulated in 1952 by D.F. Votaw and A. Orden [1] as a type of transportation problem. The mathematical model of the assignment problem for parallel processing can be described by an objective function minimizing the total cost of realizing processes:

$$\min z : z = \sum_{i=1}^{n} \sum_{j=1}^{n} k_{ij} \cdot x_{ij} \ , \tag{1}$$

and the following constraints:

$$\sum_{i=1}^{n} x_{ij} = 1, \quad j = 1, 2, ..., n \ , \tag{2}$$

$$\sum_{j=1}^{n} x_{ij} = 1, \quad i = 1, 2, ..., n \ , \tag{3}$$

$$x_{ij} \in \{0,1\}, \quad i = 1, 2, ..., n, \quad j = 1, 2, ..., n \ , \tag{4}$$

where:

x_{ij} – a binary variable for modeling a decision of selecting processes' modes; the variable assumes the value of 1 if the activity *i* is to be executed by the resource (crew) *j*, and equals 0 in the other case.

According to equations (2) and (3), considering equal numbers of crews and activities, each crew may be assigned only to one process and each process may be realized by only one crew.

H.W. Kuhn [2] in 1955 created the Hungarian method – exact algorithm for solving the model. He combined the ideas of two Hungarian mathematicians: D. König [3] and J. Egerváry [4]. The method finds an optimal assignment for a given square cost matrix, and consist of five steps [2, 5–7]:

Step 1 – Subtract the smallest entry in each row from all the entries of its row.

Step 2 – Subtract the smallest entry in each column from all the entries of its column.

Step 3 – Construct a minimal number of lines, which covers all the zero entries of the cost matrix with k_{ij}.

Step 4 – If number of covering lines is *n*, then it is complete. Otherwise, proceed to Step 5.

Step 5 – Determine the smallest, uncovered entry and subtract it from uncovered rows, and then add this entry to each covered column. Repeat Step 3.

The bottleneck assignment problem is one of the extensions of the classical formulation. It consist of the minimization of the project makespan – maximal duration of processes realized in parallel (each demanding a different crew):

$$\min z : z = \max \sum_{i=1}^{n} \sum_{j=1}^{n} t_{ij} \cdot x_{ij} \tag{5}$$

subject to the same constraints and definitions as in the classic assignment problem.

In 1959 O. Gross [8] created an algorithm which is used for solving this kind problem. It may be described as follows:

Step 1 – Begin with any of feasible solution, e.g. $x_{ii} = 1$, I = 1, 2, …, n, set of chosen entries – $B = \{t_{ij} : x_{ij} = 1\}$.

Step 2 – Compute $V = \max\{t_{ij} : x_{ij} = 1\}$.

Step 3 – Locate a cycle, which begins and ends at V as follows:

Step 3a – from V go to entry in its column with cost less than V,

Step 3b – from not chosen entry go to the entry from B in this row; if such cycle no exist, then is done.

Step 4 – Reverse the assignments along entries, which take part in previous steps. Let $x'_{ij} = 1 - x_{ij}$ for participating entries in Step 2. Proceed to Step 2.

3. Assignment problem formulation for serial processing

After completing each serial process, the renewable resources become available again and may be assigned to succeeding activities. Therefore, the constraint (2) in the classical formulation doesn't hold in this case. For each process, the whole set of crews is considered as the feasible solution space – in the problem of minimizing project duration as well as cost, aappropriate modes should be selected with the shortest duration for each process or with minimal cost, respectively.

Assuming that the processes sequence will be repeated continuously in d identical work zones (units), the objective function of minimizing project duration should be modified as follows:

$$\min z : \ z = (d-1) \cdot \max\{t_{ij} \cdot x_{ij}\} + \sum_{i=1}^{n} \sum_{j=1}^{n} t_{ij} \cdot x_{ij} \ . \tag{6}$$

The mathematical model (converted to linear form) with binary variables for many practical instances may be solved using any commercial optimization software.

4. Assignment problem formulation for hybrid processing

A construction project can be modeled as an activity–on–node network. Precedence relations between activities are modeled by a graph $G = <V, E>$, directed and acyclic, with a single initial node and a single final node, where $V = \{1, 2, \dots, n\}$ is a set of activities, the edges (or arcs) $E \subset V \times V$ represent precedence relations between activities. R is the set of resources – crews or contractors – available to the project. Variables s_i, $\forall i \in V$, stand for activities' start times.

Resources can be assigned to a number of processes, but not at the same time. Therefore, a set of processes' pairs J $V \times V$ can be defined, which can potentially be executed in parallel ($(u, v) \in J \Leftrightarrow u < v$ and activities u and v do not lie on the same path of the project network). In the case that the resource j ($x_{ij} = 1 \wedge x_{vj} = 1$) is assigned to a pair of processes $(u, v) \in J$, these processes cannot run at the same time, but have to be completed in sequence. The sequence is modeled by means of binary variables: $y_{uv} \in \{0, 1)$, defined for $\forall (u, v) \in J$. The variable y_{uv} equals 1 if the activity u is to be completed before activity v, and it equals 0 in the other case.

The decision making process is aimed at selecting options of resource assignment and scheduling them in such a way that project duration is minimal. To solve the problem, a mixed integer (binary) linear program is developed to model the construction project scheduling problem. The mathematical model used for this problem is described as follows:

$$\min T : \; T = s_n + D_n \tag{7}$$

$$D_i = \sum_{j \in R} t_{ij} \cdot x_{ij}, \qquad \forall i \in V \tag{8}$$

$$\sum_{j \in R} x_{ij} = 1, \qquad \forall i \in V \tag{9}$$

$$s_1 = 0 \tag{10}$$

$$s_i + D_i \le s_l, \qquad \forall (i, l) \in E \tag{11}$$

$$s_u + D_u \le s_v + M \cdot (1 - y_{uv}) + M \cdot \left(2 - x_{uj} - x_{vj}\right), \qquad \forall (u, v) \in J, \forall j \in R \tag{12}$$

$$s_v + D_v \le s_u + M \cdot y_{uv} + M \cdot \left(2 - x_{uj} - x_{vj}\right), \qquad \forall (u, v) \in J, \forall j \in R\,. \tag{13}$$

$$s_i \ge 0, \qquad \forall i \in V \tag{14}$$

$$x_{ij} \in \{0,1\}, \qquad \forall i \in V, \forall j \in R \tag{15}$$

$$y_{uv} \in \{0,1\}, \quad \forall (u, v) \in J\,. \tag{16}$$

The objective function (7) minimizes total project duration. Equation (8) determines duration D_i of a activity i – it has been introduced as an auxiliary formula to simplify the formulas (7) and (11)–(13). According to condition (9), each activity can be executed in only one way – as selected from available options. Execution of the first activity of the project (i.e. a activity that has no predecessors) starts at the moment of 0 (10). Condition (11) defines the successors' start dates as "not earlier than their predecessors have been completed".

Formulas (12) and (13) are introduced to define process start times $(u, v) \in J$. If these processes are not to be executed by the same resource j, $(x_{ij} = 0 \vee x_{vj} = 0)$, both of these conditions are automatically met (M is an arbitrarily assumed, sufficiently large constant), and the processes may run concurrently. If the same resource j is assigned to them $(x_{uj} = 1 \wedge x_{vj} = 1)$, and if the variable y_{uv} assumes the value of 1, then (in accordance with condition (12)), process v can only start after process u has been completed; in this case, condition (13) is automatically fulfilled. If the variable y_{uv} equals 0, then process v must be completed before u has been started – according to condition (13) and condition (12) is met automatically.

The problem of project cost minimization is trivial and in the optimal solution the crews with the lowest cost for each process are assigned to realize it. Because the project duration for this assignment may be unacceptably long, the objective could be modified as follows:

$$\min K: \ K = \sum_{j \in V} \sum_{j \in R} k_{ij} \cdot x_{ij} \tag{17}$$

and the following constraint needs to be added to assure not exceeding the deadline $T_{d.}$

$$s_n + D_n \le T_d \,. \tag{18}$$

5. Example

Durations (in days) and costs (in monetary units) for completing a particular processes by particular crews in an example project is presented in matrices **T** and **K** respectively.

$$\mathbf{T} = \begin{bmatrix} 9 & 7 & 6 & 5 & 4 \\ 6 & 5 & 8 & 6 & 4 \\ 3 & 5 & 2 & 5 & 5 \\ 4 & 4 & 4 & 3 & 4 \\ 6 & 5 & 8 & 7 & 6 \end{bmatrix}, \qquad \mathbf{X}_{\mathrm{I}}^{1} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 \end{bmatrix}.$$

The hybrid precedence relations of the processes is settled according to the technological constraints and shown in Fig. 2.

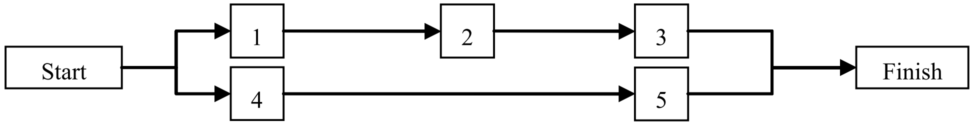

Fig. 2. Project network (example)

There are two optimal solutions of the assignment problem for parallel processes (with minimal project cost of 19 monetary units) obtained using the Hungarian algorithm:

$$\mathbf{X}_{\mathrm{I}}^{1}=\begin{bmatrix}1&0&0&0&0\\0&0&1&0&0\\0&1&0&0&0\\0&0&0&0&1\\0&1&0&1&0\end{bmatrix},\qquad \mathbf{X}_{\mathrm{II}}^{1}=\begin{bmatrix}0&0&0&1&0\\0&0&0&0&1\\0&0&1&0&0\\1&0&0&0&0\\0&1&0&0&0\end{bmatrix}.$$

The Hungarian algorithm prompts that there are three different optimal solutions obtained for the original assignment problem with minimal sum of processes' durations (20 days):

$$\mathbf{X}_{\mathrm{II}}^{2}=\begin{bmatrix}0&0&0&0&1\\0&1&0&0&0\\0&0&1&0&0\\0&0&0&1&0\\1&0&0&0&0\end{bmatrix},\qquad \mathbf{X}_{\mathrm{II}}^{2}=\begin{bmatrix}0&0&0&0&1\\0&1&0&0&0\\0&0&1&0&0\\0&0&0&1&0\\1&0&0&0&0\end{bmatrix},\qquad \mathbf{X}_{\mathrm{II}}^{3}=\begin{bmatrix}0&0&0&0&1\\1&0&0&0&0\\0&0&1&0&0\\0&0&0&1&0\\0&1&0&0&0\end{bmatrix}.$$

The solution $\mathbf{X}_{\mathrm{II}}^{1}$ is also obtained by means of the algorithm by Gross. The minimal duration for the bottleneck assignment problem is 5 days. Because the solutions for both the bottleneck and the original assignment problems are the same, so this is also the optimal crew assignment for the sequence of processes repeated in different units (regardless of the units number).

The optimal solution for crew assignment processes with hybrid precedence constraints are as follows:

$$\mathbf{X}_{\mathrm{III}}=\left[x_{ij}^{opt}\right]=\begin{bmatrix}0&0&0&0&1\\0&0&0&0&1\\0&0&1&0&0\\0&0&0&1&0\\0&1&0&0&0\end{bmatrix}.$$

The minimal project duration for a given network is 10 days. Solution of the mathematical model (7)–(16) based on the above input values was found by means of LINGO 12.0 Optimization Modelling Software by Lingo Systems Inc.

6. Conclusions

Scheduling with the allocation of constrained resources, particularly for skilled labor, is a major challenge for almost all construction projects. Most existing techniques for project scheduling consider a single–skilled resource strategy where each worker or crew is assumed to be of one particular trade. This strategy may lead to inefficiencies in labor utilization, which can also be reflected in increased project durations and unnecessary costs. In practice each construction contractor or crew can possess several skills at different proficiency levels, i.e. they are able to perform more than one type of work (construction process), each at specified times and costs. The assumption that each worker may possess multiple skills which could allow them to participate in any activity that fits one of their skills, can improve project efficiency in terms of project cost and duration.

The resources assignment models presented in the paper can help managers in determining a strategy for crew or bids selection.

For the case of parallel processing there are exact algorithms available for solving assignment problems with low computational effort. For hybrid processing options, the problems analyzed in this paper can be considered as an extension of the Resource–Constrained Project Scheduling Problem (RCPSP) which is NP–hard. Exact algorithms may be not efficient to solve complex practical problems, therefore developing heuristic solving procedures is recommended for further research.

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METHODICAL BASIS OF PLANNING IN PROPERTY MANAGEMENT

METODYCZNE PODSTAWY PLANOWANIA W ZARZĄDZANIU NIERUCHOMOŚCIAMI

A b s t r a c t

This paper presents the elements, the goals and the functions as well as the rules for the elaboration of a property management plan. The authors analyzed its importance in the decision-making process (the immediate and long-term decisions) concerning property management. Particular attention has been paid to the multifaceted character of this problem.

Keywords: management plan, property

S t r e s z c z e n i e

W artykule przedstawiono elementy, cele i funkcje oraz zasady opracowania prawidłowego planu zarządzania nieruchomością. Przeanalizowano jego znaczenie w procesie podejmowania decyzji doraźnych i długoterminowych dotyczących zarządzania nieruchomością. Zwrócono uwagę na wielopłaszczyznowy charakter tego zagadnienia.

Słowa kluczowe: plan zarządzania, nieruchomość

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1. Introduction

According to modern theories of management, planning (as more or less formalized procedure for determining the activity goals and the methods and the means of their implementation) is one of the most important tools in the management process. This function initiates, directs and organizes the management process and enables effective control of planning and actively tracks results [10]. As a result of procedures which help in the implementation and formalization of planning decisions, a **business plan** also called a **conducting business plan**, **an economic plan** or **an action plan** is used. Such a plan is called the property management plan.

The main subject of this paper is to present a methodical concept of the elaboration of a typical property management plan. The authors paid particular attention to the goals, the functions and the principles found in such plans, as well as to the planning process itself. The concept presented combines recommendations of the theory of management of economic organizations with the specifics of a property as the subject of management.

2. Definition, goals and functions of property management plan

A property management plan can be defined as "a compact set of documents (i.e. analyzes, forecasts and programs) which comprehensively characterize a property (or a group of properties), the market surrounding it, as well as (agreed with an owner) a property managers goals and tasks in relation to the specific property, and the best methods and necessary means of achieving them within a specified period of time". By analogy with [8] such a plan is defined as a verbal and numerical description:

– the resources at the disposal of a property manager (i.e. building facilities, structures, equipment, premises, funds, management company staff and external contractors and documentation as well as other available sources of information about a property) including the strengths and the weaknesses of a property,
– the goals, the expectations and the opportunities of property owners and the necessary improvements and facilities resulting from the users needs and preferences,
– the existing state and trends of changes in the surroundings, including the opportunities and threats arising from the state of the market and the level of competitiveness of the services provided,
– the directions and the variants of planned, long-term activities in the following areas: technical, economic and financial, organizational and social management,
– the procedures and the operational tasks to be performed,
– the schedules and budgets concerning the implementation of planned current activities,
– the people who have to perform the tasks, and those people who have to implement a plan,
– the potential risks of the implementation of operational plans and the possible methods of bypassing threats or to weaken the threads,
– the principles and the methods used to estimate progress of the plan implementation and to verify the assumptions.

The main goal, for the authors of the plans, lies in the planning of rational, more efficient and more effective actions of a property manager in specific areas of property management, ensuring the improvement and possible development of its current operations. The following goals (among the specific goals of the elaboration of the property management plan) should be mentioned [12]:

a) obtaining thorough knowledge about a property, its technical condition and value,
b) rationalization of current methods of property management in terms of efficiency and the effectiveness of actions taken,
c) connecting the current requirements and expectations of a property owner with the realities of the property market,
d) a better match of the current needs and expectations reported by the users of a property,
e) ensuring continuity in the functioning of a property (regulations, safety of use, security of supply and services, insurance),
f) improving the current financial situation of a property (budget, keeping a constant level of income or increasing the incomes, reducing the costs of using and maintenance/services, improved liquidity),
g) the schedule for activities related to management, using and maintenance of a property in a not deteriorated technical conditions,
h) profitable investment in a property (repairs and modernization) related to the improvement of its standard, change of function and increase of market value.

In the property management process, a properly executed management plan plays a key role, because, it combines (in a single unit) the goal, tasks, and possibilities of their implementations. A typical property management plan, like any other business plan, should serve two main functions at the same time [4, 9], i.e.:

a) *internal* – as the primary instrument of a management team in the effective management of an entrusted property, allowing for good strategic and operational decisions; in particular, the plan determines levels of projected costs of using and maintaining the property (together with the sources to cover the costs), the necessary expenditures on repairs and investments as well as proposed methods of use the obtained reserves,
   and
b) *external* – as a necessary document for the attractiveness of a property (an investment) in the eyes of potential investors and to attract outside funds needed to finance development projects (expansion, renovation, modernization, etc.).

For an owner of a property, the property management plan is – on the one hand – an important source of information concerning the legal status, technical condition and functional state, financial situation, as well as market position, opportunities and threats in the surroundings of a property. On the other hand, the property management plan recommends the most advantageous variant of use of a property for an owner, taking possible options to sell the property and procedures in case of some crisis situations (the advisory function) into account. For a property manager, in turn, the discussed plan is sometimes an important marketing tool, where a property manager tries to demonstrate how much better he/she can work in relation to the competition, (i.e. property market knowledge, acquiring new customers, availability of funds for maintenance and development of a property). In addition, the property management plan is a form of security of interests of the parties involved and determines the limits of acceptable interference of a property manager as well as the rights of its owner. It is recommended, taking the weight of responsibility of a property manager into account, that property management plans must be an integral part of the management contract.

3. Rules of elaboration of typical property management plan

It should be emphasized that there is no single, accepted and universally applicable standard of a property management plan [11]. This is due to the fact that modern planning – in fact – is an active and creative management tool, taking the specificity of the subject of the plan into account against a diverse and changing surrounding of a property. Moreover, the fact that there are many types of properties and types of owners on the property market, as well as different negotiating procedures of determining the scope of the rights and responsibilities of a property manager in the management contract, which – in practice – lead to an elaboration of precise standards of the plan, therefore, can only be sought in certain model solutions.

Below, the authors present selected theoretical rules (the assumptions) for the elaboration of the property management plans [12]. These rules apply to the conditions of typical (universal) plans. Due to their general character, these rules apply in most planning cases (apart from the type of property and the property manager's competence scope).

1. The subject of the plan is a property (or a group of properties) which is a building facility legally separated, which operates independently in the following surroundings: the property market, economic and financial, social, legal/lawful, technical condition and further information. All of the above determines and limits activities related to the subject of the plan;
2. The property management plan is a sort of the plan which is elaborated and implemented by a property manager after prior approval by an owner (or owners). Therefore, the content of the plan should take the scope of rights and obligations of a property manager written in a contract about a property management and concluded between the author of the plan and the owner of the property into account. However, it should also be emphasized, that a professional management plan should include the widest possible scope of the property manager's competence in relation to the property, which is entrusted to him – so not only the activities of routine management, but also activities beyond the ordinary management (such as: repair work and new construction work). This is clear from the definition of the property management contained in the Act;
3. In the process of the elaboration of a property management plan, one should follow the rule of limited autonomy to formulate the planning goals. Because, the goals of the plan should be closely coupled with the real goals and the expectations of an owner (or owners) of a property. It is necessary to introduce the procedure of planning the possibility of making a professional verification (by a property manager) owners' goals and expectations, which have an unrealistic character, are against the law or which are against the code of professional ethics;
4. The property management plan identifies and then verifies the owner's goals associated with the property as a result of detailed analysis and estimations of the management subject and its surroundings. Referring to the future, such a plan should clearly identify the methods and means of achieving the goals, as well as the risks and the methods of controlling their implementation;
5. The property management plan should implement the principle of the best and the most intensive use of a property, taking the overall constraints and opportunities (strengths and weaknesses) associated with the property, as well as the opportunities and the threats from its surrounding into account;

6. The property management plan must skillfully connect the long-term goals (repair work and new construction work) associated with a property with the short-term goals (the use and the maintenance). The long-term goals (directional) are carried out through the selection and implementation of the most efficient (reasonable investment) variants of the long-term plan (the strategic level – the period of 3÷5 years). In accordance with the rule: "a top-down approach", the assumptions of the long-term plan (the strategic plan) are subordinated to the specific actions with an operational character in the annual action plans included in the form of budgets and schedules [3, 6];
7. Between the long-term plan (the strategic plan) and the annual plans (the operational plans) there is some feedback. A change in the situation on the property market or in the management subject, the change to the owner's goals or the problems associated with the implementation of the previous annual plan, which might be the reasons for periodic verification of the long-term plan;
8. The property management plan should be a compact and stapled dissertation. The title page should include the title and the address of a property, as well as the author's signature. The text should be stylistically composed and logically divided into chapters and sections. The authors should use the precise language and should avoid non-essential details. It is appropriate that the text of the plan contains some photographic documentation and attachments, which – if necessary – can be placed in a separate volume.

4. Procedure of elaboration of property management plan

The examined procedure is presented on the Fig. 1, in the form of the algorithm with the established rules, indications of the general management theory [1–7] and the recommendations [13] taken into account. The algorithm shows that the planning process begins from the identification and analysis of the goals and plans the property owners expectations. At this stage of the procedure, apart from the owners organizational and the decision-making process, a property manager should generally refrain from any polemics and estimation of the proposed validity actions by customers. A property manager should rather concentrate on the identification of the real financial and organizational capabilities [12].

Subsequently, the block of analyzes consists of three phases: the analysis of basic information about a property, the market analysis and the analysis of the financial situation of the plan subject. It should be emphasized, that this type of analysis, carried out during the management plan elaboration, have a complex character because they concern not only the legal and technical-functional state of a property, but also its financial situation and the method of its use and management. However, the estimation of a property value, assuming the current method of property use, is an important element of the current financial analysis. After this a strategic analysis, applying the so-called "SWOT method" is carried out. This method enables the identification of real problems to be solved by taking the technical range of management into account (to make sure the technical condition of the property does not worsen) as well as the organizational and the social range of management [5]. The list of the strengths and weaknesses of a property with its opportunities and threats (arising from its surroundings) is the basis for formulating the goals of the plan. This is done by verifying the previously identified goals and the owners' expectations. The strategic goals (the long-term goals) and the operational goals (the current goals) might indicate the need to perform certain actions by the management team in order to achieve the desired state of the property [10]. In each case, they are the result of the mission of a property – i.e. the basic reason for its existence and use. For example, in the group of public properties or building society properties, the mission usually results from the content of adequate national laws acts [12].

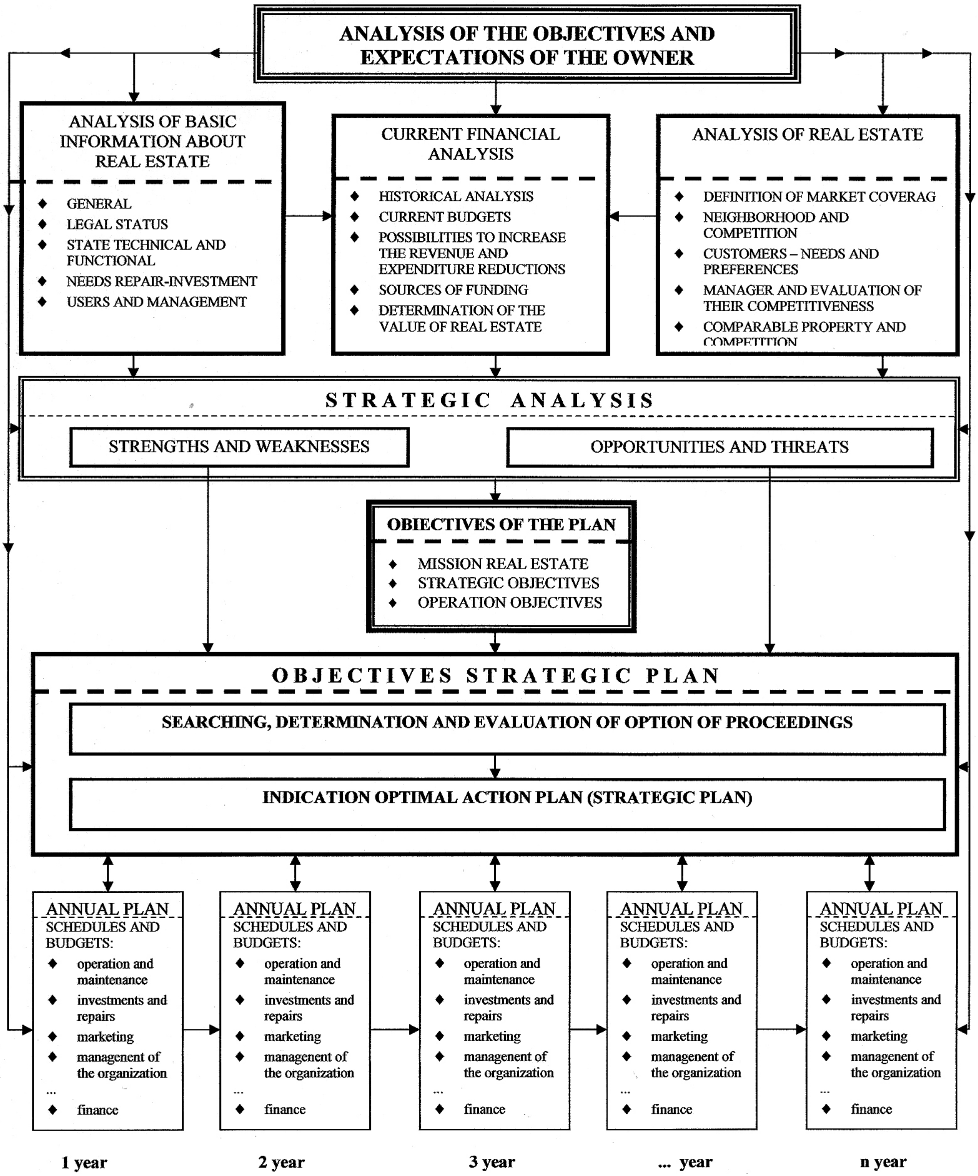

Fig. 1. Algorithm of planning in property management

Next, having a clarified list of management goals and an elaboration of assumptions for the strategic plan (the long-term plan). The strategic plan is a plan of directed actions, aimed at ensuring the optimal method of property use and management.

In general, it does not have a formalized form, and the analyzed solutions have a significant degree of generalization [2, 3]. This is primarily done to determine what actions must be taken in order to realize the most preferred and most effective methods required for achieving the long-term goals. The term assumptions of the long-term plan are made through the application of the successive approximations method – through the creation and estimation of several variants of the proceedings. This variant, which in the estimation procedure, proves to be the most cost-effective and efficient in the implementation (in terms of assumed goals) should be considered as the strategic plan (the long-term plan).

The final step in the presented procedure is the elaboration of the operational plan of action for the coming year (counting from the end of the planning work). This plan should be clearly coupled with the directional assumptions established in the strategic plan. It has the character of an implementation plan, therefore all data (regarding incomes and outgoings) should be compared accurately – divided into particular months of the operating year (a calendar year) which enables forecasts to be carried out in an easier and more accurate way. The basic form of the operational plans are schedules and budgets [3, 6]. Therefore, it is proposed that the annual action plan consists of, among others, the following schedules: using and maintenance of property, investment and repairs, marketing (if necessary) and organization of management. Then, these schedules should be "stapled" by the financial plan of a property consisting of the operating budget, capital budget (repair) and cash flows. It is important that the individual linear items of incomes and outgoings corresponding to the method of accounting procedures, as this will allow a property manager efficient control of the plan at any time. Before the end of the first operating year a property manager elaborates an action plan for the next year, taking the assumptions of the strategic plan and the results obtained in the first year into account. After expiry of the period for which the strategic plan was elaborated, the management cycle ends and a new plan should be elaborated, which takes new circumstances into account.

5. Conclusions

1. A typical property management plan is a compact set of documents (i.e. analyzes, forecasts and programs) which comprehensively characterizes a property and its market surrounding, as well as – goals and tasks of a property manager agreed with an owner in relation to a property and the best methods and the necessary means for achieving them within a specified period of time. This plan – as a set of market-oriented documents – reveals, releases and realizes the potential of opportunities in properties;
2. Property management plans include a wide area of problems related to property functioning: the technique (i.e. maintenance, reparations, repairs and investments), finance (budgets), people (the users' needs and preferences) as well as management organization. This allows the property management plans to be classified as a group of plans with a problematic character;

3. A property management plan should be the basic tool of a professional property manager as this plan is a reliable way of directing and organizing the manager's activities and enables effective control of implementation. The plan also reduces risk and uncertainties associated with the business;
4. The property management plan does not ensure success in management, however, the management business, without any plan, is an improvisation – it is a set of actions taken accidentally. Although, there is no single, perfect management plan, it is desirable to elaborate one or more professional standards in this field, which will greatly facilitate and standardize the practical activity. The subject should therefore gain a deeper interest in the organization of professional property managers.

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TECHNICAL TRANSACTIONS | **CZASOPISMO TECHNICZNE**
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2-B/2014

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STUDIES OF FACTORS AFFECTING WORKFORCE PLANNING IN CONSTRUCTION WORKS

BADANIA CZYNNIKÓW WPŁYWAJĄCYCH NA PLANOWANIE ZATRUDNIENIA PRZY REALIZACJI ROBÓT BUDOWLANYCH

A b s t r a c t

Planning the course of construction works is complex and complicated, requiring reflection on many aspects related to the implementation of the project. High importance is placed on duration and cost of the project, as well as the separation of necessary resources. This article deals with the subject of planning the size of the workforce for a project, presenting widely available workforce planning methods, in accordance with academic approaches. A survey was conducted among Polish construction contractors – with differing scopes and ranges of activities, regarding practical methods for determining the size of the workforce. Factors that influence the size of a construction team were also investigated. The results obtained will develop with further research in this area.

Keywords: workforce planning, construction teams

S t r e s z c z e n i e

Planowanie przebiegu robót budowlanych jest zadaniem złożonym i skomplikowanym, wymagającym zastanowienia się nad wieloma aspektami związanymi z realizacją inwestycji budowlanej. Jednym z nich, mającym duże znaczenie dla czasu i kosztów przedsięwzięcia, jest rozdzielenie niezbędnych zasobów. W artykule podjęto temat planowania poziomu zatrudnienia dla realizacji robót budowlanych i przedstawiono ogólnodostępne metody planowania zatrudnienia, zgodne z podejściem akademickim. Przeprowadzono ankietę wśród polskich wykonawców budowlanych – o różnym zakresie i zasięgu działalności, na temat praktycznego sposobu ustalania wielkości zatrudnienia. Badano również czynniki, które wpływają na liczebność brygad roboczych. Otrzymane wyniki zostaną rozwinięte o dalsze badania w tym zakresie.

Słowa kluczowe: planowanie zatrudnienia, brygady robocze

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1. Introduction

Shaping the size of the workforce while guaranteeing the required level of expertise throughout the duration of the works is a matter that requires careful consideration. Widely available workforce planning methods, consistent with the academic approach, are based on work time standards, available, e.g. in builder's price books. The builder's price book contains information on the composition of the construction crew – areas of expertise, who should be included and the quantitative proportions between them. Please note that according to the builder's price book, for the fulfilment of each particular job, a planned construction crew should be included, and that the crew should remain unchanged until the end of work. In addition, and as a rule, each employee is treated as unqualified or qualified only in one area. Planners are often faced with the problem of matching entries in the builder's price book to the actual work. It is not always a representation of reality, or as accurate as we would like it to be.

In the literature available, it is not easy to find a good definition of how to plan the workforce, other than by using the database of builder's price books. To investigate what else guides Polish builders and what factors they take into consideration while selecting employees – a survey was performed. The purpose of this article is to present the results of research on the factors influencing the planned level of employment and to indicate the possibility of using results obtained in practice.

2. Factors affecting workforce planning in construction works

The project-based nature of the construction process entails concerns regarding resource planning at site level. Ensuring the adequacy of construction staff and the trades which make up project teams is a vital task. To assess long term staffing needs, an organization must be able to precisely determine the demand for personnel in each of the various discipline in advance. Skilled trades are difficult to just hire off the street as the demand arises. Instead, a method of estimating a project's requirement for personnel would help the organization in human resources planning, budgeting, and would also help each functional group to better plan its work. Labor costs make up a significant portion of the total cost of a construction project. It is therefore critical for contractors to assess the manpower required in executing future projects.

Factors affecting the level of employment of workers in the implementation of construction works are the subject of interest of researchers in many countries. One of the most extensive research projects on this subject was carried out in 2008, the results of which are presented in [1]. It was carried out in the Hong Kong construction market on the basis of 54 projects.

The construction method of an individual project determines the site labor input and mix of skills. The increasing use of prefabrication, production activities off-site, and the use of other engineering demanding construction methods would cause an increase in plant and equipment operators and prefabricated element erectors. The degree of mechanization and automation utilization also critically influences the labor demand at site level, as labor and capital are the major inputs. In general, the greater the input of capital, the less labor is required because automation tends to be labor saving. Labor requirement can also be affected by the management skills of project team. Better coordination and utilization of plant and labor on site leads to a reduction in manpower requirements.

3. Research method and research sample

In order to discover the criteria which determines Polish building planning and the workforce required for the execution of construction works, a survey was carried out. The questionnaire is available on the Institute of Management in Construction and Transport of the Department of Civil Engineering of the Krakow University of Technology website from November 2013. The results presented in the article relate to the period from January 2014. Twenty two responses from construction contractors were obtained. The survey consisted of two main parts. The first part concerned the characteristics of the company and the second the method and basis of workforce planning, as well as the factors that in the respondents' opinion influence the decisions made.

In the first part of the questionnaire contained questions regarding six aspects characterising the company. These were: the scope of the company's activities, the average number of employees, the range of the company's activities, the average number of contracts for construction works per year, the average range of the value of contracts concluded, and the nature of participation in the investment process.

Multiple answers were only possible for the first question, where respondents could provide answers other than the four proposed options. The highest percentage of responses concerned industrial building. This is due to the desire to focus on this type of construction in the future in the authors' further research. Reaching the companies, whose scope of activity includes industrial building was somewhat of a priority, although the questionnaire was also addressed to Polish construction contractors or subcontractors dealing with a different ranges of activity.

In the case of the remaining questions in the first part, it was possible to mark only one answer, which excluded all others. The purpose of the second question was the classification of companies in micro, small, medium and large companies. The division was adopted pursuant to [2], only taking the number of people employed by the company into account. Most of the companies surveyed were medium to large enterprises. The third question inquired about the range of the company. The highest percentage of responders indicated the international market. More and more construction companies expand their operations beyond Polish borders, which can be taken as a good omen for the Polish economy. Only 16% of respondents focused exclusively on the local market, which has been identified as the area of a particular province. Fourth and fifth question concerned the contracts concluded by the company – their number per year and the average range of the value of a single contract. All companies that participated in the survey enter into at least 5 contracts per year, and more than 40% over 15 contracts per year. The average value of contracts concluded in almost 50% of cases exceeds 5 million zlotys.

4. Survey results

The second part of the survey examined how respondents determine the number of workers and the duration of the works in the construction schedule. It was possible to check more than one answer a well as to put down own answers not included on the list. Two companies took advantage of the possibility of providing their own answers. The results are shown in Fig. 1.

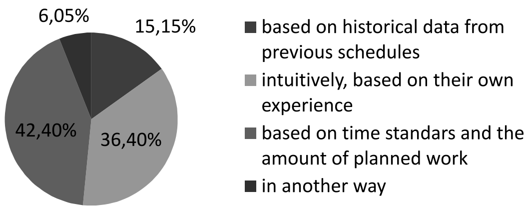

Fig. 1. Method of determining the amount of workers and duration of the works

Time standards and the amount of planned work were the most common basis for determining the amount of workers and duration of the works. This is compatible with most common academic approach. Using the standards given in the available database of builder's price books, the areas of expertise and their quantitative proportions are determined. The next step was to adopt the number of units deemed as leading in the execution of works under consideration and to proportionally select the level in other areas of expertise. And on what basis is the number of employees in the leading unit selected? To answer this question, 12 factors were evaluated, which in some way can affect the decision. If the planner chooses the number of employees intuitively, his intuition must also be influenced on different factors related to the implementation of the project.

Respondents evaluated 12 factors selected partly on the basis of the literature [1], partly based on discussions with contractors or proposed by the authors. In addition, each person filling out the questionnaire had a chance to add and evaluate factors which were not on the list, but which were important according to and for the respondent.

In the last question, the participants rated according to their opinion the level of influence of each factor regarding the employment decisions made. Calculations were then carried out based on the obtained data, according to the method described below.

Each factor was given an average score, using the rule:

$$\overline{x} = \frac{1}{N}\sum_{i=1}^{n} x_i \tag{1}$$

where

x_i – evaluation mark assigned to criterion,
N – general number of answers;

Importance index was obtained in the following way:

$$I = \overline{x}\frac{100}{5} \tag{2}$$

Thanks to these calculations, the rank of each response was obtained, allowing arranging the factors from most to least important.

Table 1

Average scores and validity indexes of factors

Name of factor	Average factor rating	Importance index
1. Imposed deadlines for the implementation of various works and the contractual deadline for completion of construction	3.55	71.0
2. Amount of work	3.50	70.0
3. Construction technology used	2.95	59.0
4. Type of work	2.87	57.4
5. Effective management of the project by the main contractor	2.86	57.2
6. Degree of prefabrication of materials	2.77	55.4
7. Degree of mechanisation of work	2.52	50.4
8. Employee qualifications	2.50	50.0
9. Physical conditions at the construction site (e.g. difficult geotechnical or hydrological conditions, physical obstructions)	2.50	50.0
10. Availability of workers	2.41	48.2
11. Degree of cooperation between the designer and the contractor	1.82	36.4
12. Contract value	1.20	24.0

Data presented in Table 1 shows that the factors having the greatest impact on the planned workforce are:

- Imposed deadlines for the implementation of various works and the contractual deadline for completion of construction,
- Amount of work,
- Construction technology used.
- Factors having the least impact on planning the workforce were:
- Availability of workers,
- Degree of cooperation between the designer and the contractor,
- Contract value.

Respondents also reported further factors that they believe are relevant to the planning of workforce. They are “Construction plan” and “Efficiency of employees”.

Most of the results were not surprising. It seemed obvious that contractors wishing to meet imposed deadlines will try to adapt the size of the team according to deadline requirements. Surprisingly, disregarding the contract value actually has a positive influence, although this being linked to the amount and scope of work, and normally exerts a strong influence on the number of workers. The reason for disregarding contract value is perhaps due to the fact that the value of the contract is not directly associated as a factor related to the size of the workforce and it doesn't always have a direct impact in this sense. It is also related to the cost of materials used, or special systems, which in the case of specialised facilities such as industrial facilities, can greatly affect the cost of the project.

Comparing results of the the Polish study with the one carried out in Hong Kong, we can however see that factors relating to the value of the contract were still rated very highly. The results from [1] indicate also that project labor demand depends not only on a single factor, but a cluster of variables related to the project characteristics, including construction cost, project complexity attributes, physical site condition and project type.

5. Possibilities for the use of research results

These results can help in making a model which can be used to predict the demand for workforce in a particular construction project.

Although a number of studies were conducted to predict the manpower demand at project level, they were merely modelling simple relationships between manpower requirements and construction cost or productivity rates. In [1] labor records and project information collected for developing labor demand prediction models, applying multiple regression analysis. 11 manpower demand forecasting models were developed for the total labor as well as essential trades. The models were then verified by comparing the predicted values with actual values. Accompanied by the results of the diagnostic tests, it was confirmed that the forecasting models are robust and reliable.

This is not the only method that can be used to build the model supporting workforce planning. It is planned to use the research carried out in Poland for the work on a model based on the principles of fuzzy logic. Previous studies have successful demonstrated the use of fuzzy sets theory for quantifying the imprecision associated with planning in construction works [3–5].

In the simplest terms, the results of this research will help to determine the relationship between the factors and the number of employees. For this purpose, two sets will be built – a set of factors (Z) and a set of the workforce sizes (U). Most of the factors affecting the size of a construction crew are qualitative. Their value (impact) is defined verbally as "very important", "important", "totally insignificant".

To define the problem and embody the parameters of the phenomena, it is planned to use the concept of fuzzy relations according to [6]. Each pair of arguments $(x, y) \Leftrightarrow (z, u)$ is assigned a rank (measure) of membership, which expresses the intensity of the occurrence of a relation between Z and U. It is assumed that the Z and U sets – as fuzzy sets, defined in terms of fuzziness, which can be linked together in a certain relation. This led to the definition of the concept of fuzzy relations in the following form [7]:

A binary relation R between two sets $Z = \{z\}$ and $\underline{U} = \{u\}$ is such a relation, which is defined as a fuzzy set defined on the Cartesian product $Z \times U$:

$$Z \times U = \{(z,u) : z \in Z, u \in U\} \tag{3}$$

So it is a set of pairs:

$$R = \{(\mu_R(z,u),(z,u))\}, \forall z \in Z, \forall u \in U \tag{4}$$

where:

μ_R:$X \times Y \rightarrow [0, 1]$ – the membership function of the fuzzy relation *R*.

Therefore, a fuzzy relation can be written in the form:

$$R = \sum_{z,u} \mu_R(z,u)/(z,u) \tag{5}$$

Fuzzy relations between *Z* and *U* will show to what extent the fuzzy factor affects the size of the workforce. For all of these relations, the following should be defined:

- The domain of fuzzy relation *R*, called the first projection of a fuzzy relation and marked *domR*:

$$\mu_{domR}(z) = \vee_{z \in Z} \mu_R(z,u) \Leftrightarrow \vee_{i=1}^{n} z_i = \max\{z_1, z_2, \ldots, z_n\} \tag{6}$$

- The range of fuzzy relation *R*, called the second projection of a fuzzy relation and marked *ranR*:

$$\mu_{ranR}(u) = \vee_{u \in U} \mu_R(z,u) \Leftrightarrow \vee_{j=1}^{m} u_j = \max\{u_1, u_2, \ldots, u_m\} \tag{7}$$

- The elevation of fuzzy relation *R*, called the global projection of a fuzzy relation and marked *h*(*R*):

$$h(R) = \vee_{z \in Z} \mu_{domR}(z) = \vee_{u \in U} \mu_{ranR}(u) = \vee_{z \in Z} \vee_{u \in U} \mu_R(z,u) \tag{8}$$

whereas, when $h(R) = 1$, the fuzzy relation is normal, and if $h(R) < 1$ then it is subnormal.

Designing a model for planning a labor could provide a practical and advanced tool for contractors to predict the reasonable labor required for a new construction project at the initial stage, which is valuable to facilitate human resources planning and budgeting.

6. Conclusions

The planned level of workers necessary for the implementation of construction works has an influence on the final shape of the basic elements of the construction plan. In practice, this is based primarily on existing databases of work time standards and intuition. This article has presented the results of studies on the effects of various factors on the adopted level of employment in the opinion of Polish contractors. The paper also presents possibilities for the application of the results, including the outline of a model based on fuzzy sets, which will be developed and expanded by the authors in further research.

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2-B/2014

AGATA SIEMASZKO*

PROBLEMS OF CONSTRUCTION PROJECTS REGARDING HISTORIC ROAD BRIDGES

PROBLEMY PLANOWANIA PRZEDSIĘWZIĘĆ BUDOWLANYCH DOTYCZĄCYCH ZABYTKOWYCH MOSTÓW DROGOWYCH

A b s t r a c t

The paper describes the comparison of different approaches to reconstruction and the problems in the selection of implementation for a historic bridge over the Vistula River in Tczew. A compromise reconstruction is shown, taking technical, historical and aesthetic aspects into account, as well as the needs of the local community.

Keywords: construction, reconstruction, technology, bridge, monument

S t r e s z c z e n i e

W artykule opisano zabytkowy most przez rzekę Wisłę w Tczewie. Porównano różne koncepcje jego przebudowy oraz problemy przy wyborze wariantu realizacyjnego. Przedstawiono rozwiązanie kompromisowe odbudowy uwzględniające aspekty techniczne, historyczne i estetyczne, a także potrzeby społeczności lokalnej.

Słowa kluczowe: energetyczne wykorzystanie biogazu

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1. Introduction

Tczew is a historical city with unique cultural heritage, which includes a historic bridge called “Lisewski”. The city is currently undergoing a period of renewal and revival to raise the quality of life. Being aware of and making use of specific historical monuments add to the cultural, recreational requirements of the city, and in doing so boost tourism. Due to this, the Tczew revitalization includes a reconstruction of the bridge, which is currently out of service and undergoing destruction. This is a multi-threaded and costly project which will be carried out over many years, in which the support from the EU funds is highly appreciated. The project implementation will help to restore and develop the social, cultural and tourist function for deprived areas in the region. This will be possible due to the complexity of the planned activities. An essential element of these activities is to analyze the possibility of rebuilding the bridge for reasons of cost and of image. The results of the analysis are presented in this paper.

2. Characteristics of the historic road bridge

2.1. Historical background

National road networks still operate bridges built in the mid-nineteenth century, which were pioneering at that time of construction. One of them is a bridge in Tczew, which was put into operation on October 12, 1857. The total length of the bridge was 785.28 m, one of the largest spans in Europe at that time. The supporting structure was made as three two-span steel grates in the form of a dense grid of intersecting elements.

The bridge consisted of the neo-Gothic towers founded on five bridge pillars and abutments topped with massive gates from the direction of Tczew and Lisewo (Fig. 1).

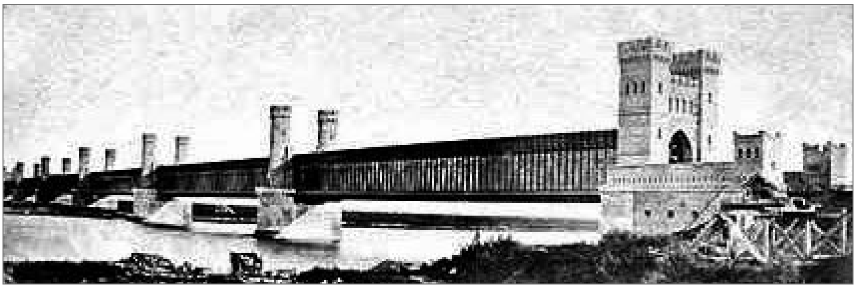

Fig. 1. Project of the bridge in the figure of Carl Lentze [3]

The architect was Carl Lentze, the author of static calculations and design solutions Eduard Rudolf Schinz, a designer of portals and towers – Friedrich August Stüler.

The conviction that this bridge is a leading design of this type on the European continent and deserves international recognition has led to enter it in the register of the “International Civil Engineering Monument” American Society of Civil Engineers: ASCE. Therefore, on

24 September 2004, it was held the unveiling of a plaque commemorating the event with the participation of representatives of state, local and Gdansk University of Technology and the U.S. Embassy in Poland [1].

2.2. Description of the current bridge structure

Due to the turbulent history, at the moment the object is composed of five different types of structures that were created at different times (Fig. 2). They are briefly described below [2].
Type I – a span no. l: the span supporting structure consists of four main girders made of rolled composite with reinforced concrete slab bridge.
Type II – spans 2 and 3: a supporting structure creates a two-span continuous grate, temporary ESTB type with driving down.
Type III – spans 4, 5 and 6 with a truss: a supporting structure form a two-span continuous grates called "Lentze grates" and are covered by the entry into the register of monuments Pomeranian province under number A-1705.
Type IV – spans 7, 8, 9: a supporting structure of spans form free supported grates, riveted, with parallel stripes of W grating with posts, driving up.
Type V – spans 10, 11, 12: a supporting structure of spans form free supported grates with a secondary hanger, riveted, with parallel stripes of grating with posts, driving down.

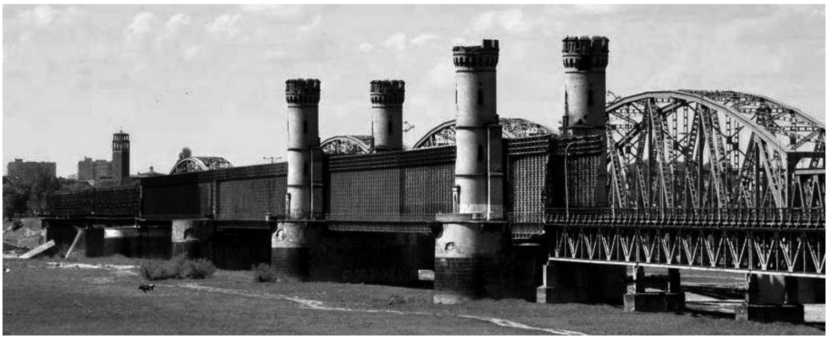

Fig. 2. A view of the current condition of the bridge

2.3. The current technical state of the object

The current overall, the general condition of the bridge is very bad. The analysis carried out showed that the object in its current state, does not meet even the lowest class E capacity according to the existing standard PN-85/S-10030 (max weight of authorized vehicles – 150kN). The capacity of individual spans is not determined by main girders, but by elements of the bridge and roadway. This forced the County Road Administration in Tczew to close the bridge to traffic. Closer observation shows localized deformations of individual elements of the grid as well as cracks and scuffs in the concrete .Water damage to the deck slab is one of the reasons for the advanced corrosion of steel parts. The precast deck panels show visible damage in numerous places, which reduce their capacity. Within the pedestrian path there are defects in the boards and railings, as well as rotten wooden elements. Deficiencies in basic security can lead to disastrous consequences. Degradation of elements of the historic brick towers can be observed as defects in brick walls, stains, numerous scratches and cracks. To sum up, all parts of the bridge require general repair or replacement, starting from the platforms and through to the main girders, elements of equipment and ending with the historic towers [4].

2.4. The importance of the object

The importance of the bridge in Tczew is very diverse. It is a symbol, a repository of knowledge, as well as a tourist attraction. Some of the functions of the monument are as following.

Table 1

The role of a bridge over the Vistula River in Tczew

The educational role	The bridge currently consists of different types of spans that perfectly illustrate the development of bridge engineering from the mid-nineteenth century to the 70's of twentieth century. It is a source of interest for students from technical high schools as well as those from construction and civil engineering backgrounds.
The economic importance.	This is certainly a historic building that could attract tourists. Expenditure on construction works are an investment that is sure to return.
The functional role	After rebuilding the monument could act as a „link" on the tourist road connecting Gdańsk with Malbork – cities with very large tourist values.
Social usefulness	The local community feels great attachment to the bridge. The object induces a sense of community identification with the place.
Political meaning	The bridge built by the Prussians became a symbol of the development of German engineering. It is one of the few remaining „miracles" of the industrial revolution. In contrast, the sacrifices made by Polish railway men, defending the bridge against seizure, was a symbol of struggle and martyrdom of the September Campaign in 1939.

3. Concepts reconstruction

3.1. Option 1 "historical"

The "historical" option involves recreating the look of the bridge as it was before 1939. The supporting structure of the bridge in this option will create nine spans visually two types, structurally three different types: the so-called "Lentze grid" will be restored, with the new grid welded to reflect the original appearance of 1912. For all spans the entire length of the bridge deck is made from an orthotropic steel plate. In addition, a pavement along the entire length of one side of the bridge is planned, while on the other side cycle path will be added [5].

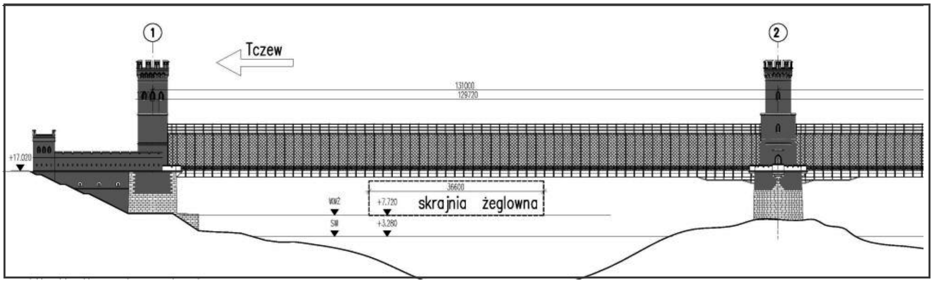

Fig. 3. Bridge project in "historical" option [5]

3.2. Option II "modern"

This option protects the traditional historic look of the bridge while at the same time establishing new structures by exchanging spans to the historic character of the object. It is also important to add all portals gates and towers in places where they were before 1939 that its appearance will refer to the characteristics of spans. Also the height of the newly designed gates and an entry portal from the Lisewo will be changed. The supporting structure of the bridge, using the "modern" option will create 10 spans and about three different types of structure. For all spans across the entire length of the bridge, the deck will be constructed of steel orthotropic plate. In addition, along the entire length of one side of the bridge is a planned pavement and the other a cycle path [5].

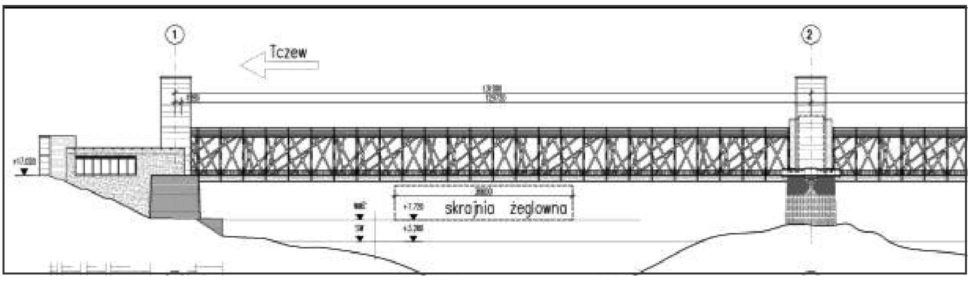

Fig. 4. Bridge project in "modern" option [5]

3.3. Materials and colors

Current historic parts of the bridge are constructed from Iron and steel bridge construction are shown in gray, clinker brick in light color (beige and sand), sand stone elements, the elements of granite stone. Supporting structures of newly built towers and gates portals are designed as reinforced concrete covered with clinker façade tiles and slabs of sandstone. The gate from Tczew side will be made from brick, stone and concrete. The applied colors on the towers are like the colors of horizontal ceramic slats and hand bricks in warm tones inspired by the bright colors of brick and stone occurring in the historic towers. Proposed color at the concept stage refers the existing materials and colors. The colors of the bridge structure have been gently emphasized and show historical and newly constructed elements, taking the stages of creating the bridge, including its elongation from the Lisewo in 1912 into account [5].

4. Analysis of the economic, technical and social aspects

Possible methods of reconstruction were analyzed in three aspects: economic – technical, taking into account the position of the conservator and ensuring the demands of the local community. Economic criterion as well as the conservational aspect pointed to a "modern" concept. Reconstruction of the bridge using the "historical" option will cost 133 mln zł (the spans and supports of the bridge will cost one hundred eighteen million zł), while in the "modern" option – 136 mln zł (the spans and supports of the bridge will cost one hundred twenty-two million zł). The cost comparison for selected elements of the two approaches are shown in figure no.5

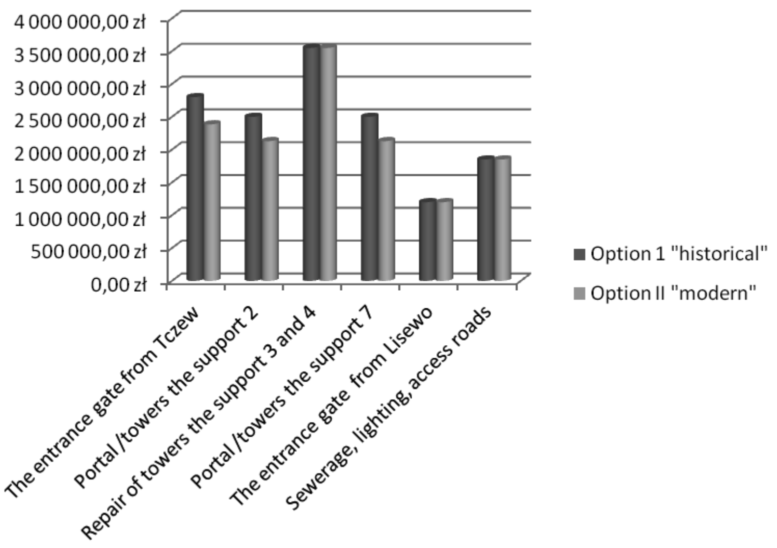

Fig. 5. Compare the costs of two variants on the basis of indicator cost estimate

In the opinion of the Provincial Conservator, the variant presented will positively affect the preservation of historical architectural value by exposing the surviving parts of the bridge from 1857.

Among the inhabitants of Tczew opinions definitely lean towards the "historical" option, which is more expensive primarily due to production of "Lenza" grates. Accordingly, the author has developed a compromise option taking into account the above demands (Fig. 6). Option compromise is a derivative of both reconstruction concepts in which the platform and supports derived from the modern concepts and the entrance gate from Tczew side and towels retain the prototype appearance. After the cost estimation can be concluded that the towers and portal made using modern technology with the historical look with facing façade tiles in the described colors reduce the investment cost of about 1.150.000,00 zł.

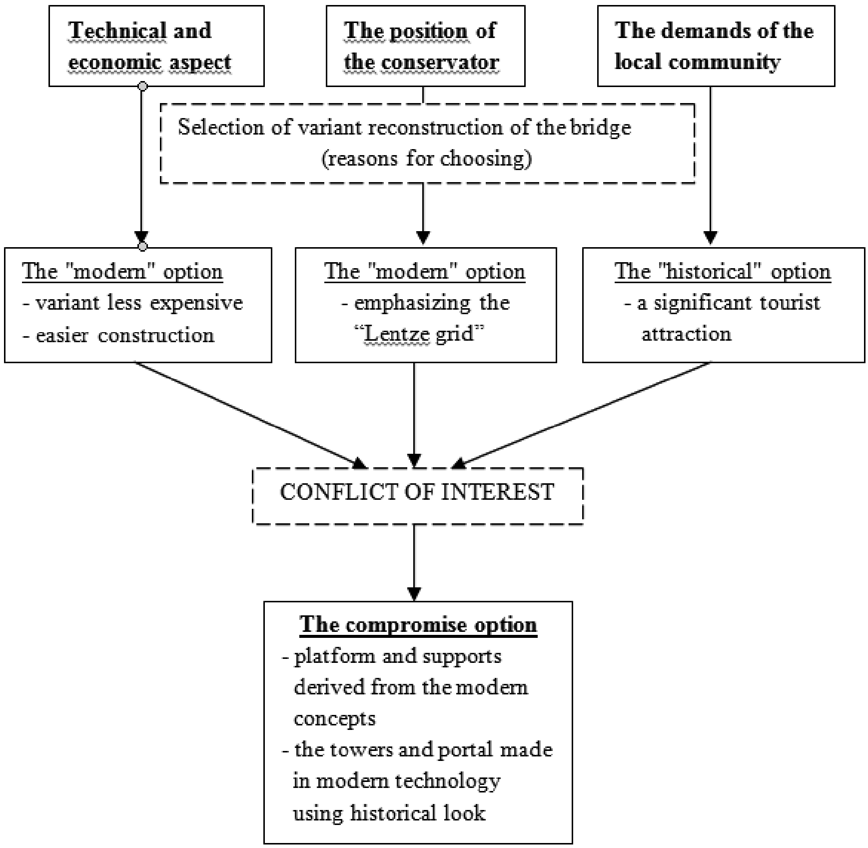

Fig. 6. Scheme for working out the compromise solution

5. Conclusions

Due to the historical character of the building – it is a wonderful monument of engineering, an object of European heritage and technical culture – thus it should be prevented from further degradation and reconstructed, so that it can actively work for many more years. The partial works covering only selected parts of the object should be avoided. Work must be carried out by the company and staff with experience in working on historic buildings.

In the event of the omission of any investment, the bridge will be subject to progressive technical degradation. The result will be a significant deterioration in the technical condition of the object and the increased risk to vehicular traffic within it. At the moment, the object is closed and traffic is directed to other crossings on the Vistula River. However, the renovation work on the border of the historic towers is carried out. An extreme result of a lack of technical improvements to the object as a result of progressive technological degradation process will result in the demolition of parts of object due to impending collapse. This option is particularly disadvantageous both for reasons of organizational functioning of Lisewo and Tczew, the protection of monuments (entered in the register of monuments) and indirect environmental hazards arising from the potential threat of the collapse of the object. Lack of investment implementation in the assumed range of road will result in significant deterioration for local traffic, particularly noticeable for the residents of Lisewo. On the basis of calculations of traffic for investment purposes, it was found that the studied object in the present day should be included to ease traffic, due to the lack of alternative means for communication road for Lisewo (with the exception of the object in Kwidzyń)

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ESTIMATING THE TIME OF BUILDING PROCESSES WITH PROBABILISTIC MODELS

SZACOWANIE CZASU REALIZACJI PROCESÓW BUDOWLANYCH Z WYKORZYSTANIEM MODELI PROBABILISTYCZNYCH

A b s t r a c t

On the basis of traditional methods for the technical normalization of working time, this present paper presents the use of probabilistic models of working processes for use when estimating the execution time for selected building processes.

Keywords: Planning and organisation in building projects, probabilistic models, risk

S t r e s z c z e n i e

Na bazie tradycyjnych metod normowania technicznego czasu pracy w artykule przedstawiono wykorzystanie probabilistycznych modeli procesów budowlanych w zagadnieniu szacowania czasu realizacji wybranych procesów budowlanych.

Słowa kluczowe: organizacja i planowanie przedsięwzięć budowlanych, modele probabilistyczne, ryzyko

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1. Introduction

Estimating the execution time for work processes has traditionally been carried out on the basis of quantitative standards which characterise processes and information (type, unit of measure, the number of units). The principal methods of quantitative standards' development, used among others to estimate the execution time for work processes, are **analytical, summary and parametrical** methods [3].

Analytical methods [17] are based on a detailed analysis of the organizational and technological execution of work and time examination, in order to identify the constituent elements of standard and irregular time. The investigation carried out for work process' components and model verification help to improve technical, technological as well as organizational aspects of process planning.

Time measurements are taken in conditions determined in prior analyses, and then average execution times for all components of the process are established. With regard to the level of complexity of the process, and based on averaged times, the planner can set up the following: **standard** of the time of working process (**simple process**), **merged standard** of the working process (**complex process**).

Splitting the standard of working time into components is carried out in a different way with reference to the work of workers and the work of machines (table 1) [3, 5].

Table 1

Structure of the standard of working time of the worker and machine in the deterministic approach (example)

1. n^r – standard of worker's working time 1.1. *tpz* – preparatory & finishing time 1.2. *tj* – unit time 1.2.1. *tw* – execution time 1.2.1.1. *tg* – main time 1.2.1.2. *tp* – auxiliary time 1.2.2. *txt* – time of technological breaks 1.2.3. *to* – attended time of workstation 1.2.4. *tf* – time for physiological needs 1.2.4.1. *tfn* – time for natural needs 1.2.4.2. *tfo* – time for the rest	**2.** n_j^m – standard of working time of the *j*-th machine 2.1. *tpz* – preparatory & finishing time 2.2. *tj* – unit time 2.2.1. *tg* – main time 2.2.2. *tp* – auxiliary time 2.2.3. *txt* – time of technological breaks or time of the idle ride 2.2.4. *to* – attended time of workstation 2.2.5. *tf* – time for physiological needs (of operators)
$n^r = tpz + tw\left(\frac{100 + to + tf}{100}\right) + txt$	$n_j^m = tpz + tg + tp + txt + to + tf$

Amongst the analytical methods, an analytical-computational method and an analytical-measuring method are distinguished. **The analytical-computational method** is applied if component times of the standard are well-known. **The analytical-measuring method** is applied in such cases when there is a lack of such data, and when it is necessary to take multiple measurements and compile the results.

Measurements and observations of working time can be carried out with the help e.g.: of **the timing** (chronometry), **shutter observation** or **the photograph of a working day**.

Summary methods [17] allow the user to establish labour standards for working process as a whole, without splitting them into components and without the analysis of standardized and irregular time. Summary methods are divided into: **estimated-experimental**, **comparative** and **statistical** methods.

Summary methods take the following into account: worker's experience (estimated-experimental method), historical data from works performed earlier, data provided from measurements of times or other information describing the actual use of working time, which allows for standard's development (comparative method) within analyses and analogies, and finally statistical data from daily or periodic reports, enabling the right standards of the time with statistical methods to be determined.

Parametric methods [3] enable the planner to develop the standard of time, based on relations defined between parameters which describe the scope of the working process as well as labour intensity.

The execution time of the simple working process constitutes the maximum time intervals necessary to complete all work components and considers demand on the working times of every kind of resource. The execution time of the simple process t_i is calculated using formula (1) and (2).

$$t_i^r = \frac{n_i^r}{k_i^r}; \quad t_{i,j}^m = \frac{n_{i,j}^m}{k_{i,j}^m} \text{ dla } j \in M_i \tag{1}$$

$$t_i = \max\left\{t_i^r, \quad t_{i,1}^m, \quad t_{i,2}^m, \quad \ldots, \quad t_{i,|M_i|}^m\right\} \cdot l_i \tag{2}$$

where:

t_i^r – execution time of the *i*-th process based on labour demand,

$t_{i,j}^m$ – execution time of the *i*-th process based on the work demand of the machine of the *j*-th type,

n_i^r, $n_{i,j}^m$ – standards of working time of worker and machine of the *j*-th type from the M_i set,

k_i^r, $k_{i,j}^m$ – number of workers and machines of the *j*-th type, realizing the *i*-th process,

i – working process' number and j – number of machine's types

l_i – range of the process (number of units).

The execution time of the complex process t^C is a sum of execution times for simple processes and the offsets (breaks) resulting from technological and organizational relations, calculated with reference to the chain of processes (paths), in which this sum achieves the maximum value.

$$t^c = \max S \rightarrow S\left\{s_q\right\}, \quad q = 1, \ldots, h \tag{3}$$

$$s_q = \sum_{p=1}^{z_q}\left(t_p^q + d_p^q\right), \quad p = 1, \ldots, z^q, \tag{4}$$

where:

t^c – execution time of the complex process,

S – set of sums of execution times of processes along s_q paths,

q – indicator of the path in the network model,

d_p^q – breaks resulting from the relation between processes (p) and (p+1) on q-th path,

h – number of possible paths in the network model,

z^q – number of processes in the q path,

t_p^q – execution time of p-th simple working process on the q path.

Table 2

Model of simple working process in deterministic approach (example)

Number of process	1	Unit of measure	m^2	Number of units	3600
Name of the process:		Removal of the fertile soil (humus) to a thickness 15 cm with using of bulldozers			
Resources				Standards of	
Kinds of resources		[units]	Number of resources	demand on work of resources	execution time
1	labour	[l-hr]	4	0.0053 [l-hr/m^2]	0.00133 [hr/m^2]
2	caterpillar dozer 74 kW	[m-hr]	1	0.0025 [m-hr/m^2]	0.00250 [hr/m^2]
Duration of the process: (max → {standard time * number of units})				9.00 [hr]	

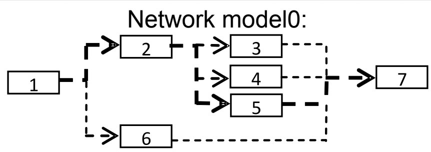
Reamarks: [l-hr] – it means man-hour, [m-hr] – it means machine-hour.

Table 3

Model of the complex working process in the deterministic approach (example)

Number of process	1	Unit of measure	m^2	Number of units	10 000
Name of the process:	Measurement and preparatory work at the surface earthworks (trough pavement parking squares), trees felling (diameter 16–25 cm) and cutting down of bushes, with their transporting (2 km) and the removal of humus (25 cm) by bulldozer.				

ID	Name of the sub-process	u.m.	Quantity	Estimated time of execution [h]	Matrix of offsets [hr]	Binary matrix of the order						
						1	*2*	*3*	*4*	*5*	*6*	7
1	measurement works	ha	1	13,80	1		1	0	0	0	1	0
2	trees felling	pcs.	500	53,50	2	12		1	1	1	0	0
3	logs disposal	l.p.	35	15,31	3		–8		0	0	0	1
4	tree stumps disposal	l.p.	85	35,70	4		–8			0	0	1
5	branches disposal	l.p.	100	40,00	5		–8				0	1
6	bush cut down	ha	1	46,25	6	12						1
7	humus removal	m^2	10 000	41,00	7			–4	–4	–4	0	
Estimating the execution time of complex process:						**148,3 [hr]**						



Remarks: [ha] – hectare, [pcs.] – pieces, [l.p.] – loading point.

A path with the maximum sum of times is established within the time analysis of the complex processes in the network model, in order to determine the course of the critical path.

2. Premises for the probabilistic model appliance

The main premises for the appliance of the probabilistic model in the building processes research is their random character. This is due to a lack in the explicit and credible estimation of results of experiments multiplied and repeated in similar or the same conditions. Repeatedly run experiments and the registration of these results, although being expensive and labour-demanding, allow for the statistical estimation of results' forecast using i.e. the average value and measurements of the changeability (variance, standard deviation).

The probability of obtaining a certain result in a single experiment or series of experiments is another helpful parameter. An appropriate and acceptable probability level lets us formulate a satisfactory and accurate forecast using statistical values. The quality of forecasts strongly influences the effectiveness of future actions' planning.

3. Characteristics of the probabilistic model

The proposed working processes' model is aimed at creating a tool for simulative estimations of execution time processes' [10]. Execution time for working process t_i is a sum of component times (table 1), hence, based on the central limit theorem, it is variable T_i that models it, which is a continuous random variable which has a distribution convergent with normal distribution.

The proposed probabilistic model of the simple working process considers both: types of working time components, included in deterministic quantitative standards of the process, and information concerning the number of working resources.

Using general properties of the expected value, that is:

$$E(a \cdot T_i + b) = a \cdot E(T_i) + b \tag{5}$$

where a and b are constant, it is possible to divide the characteristics of components' times into three groups:

- **group I** – times described by random variables normally or log-normally distributed (basic component times), defined after an empirical and/or simulation examination with the type of the distribution, the average value and the standard deviation or variance, e.g.: main time, auxiliary time (see table 1),
- **group II** – times described by the ratio a_i proportional to the sum of times established in **group I**, e.g.: attendance time for a workstation or machine, time for physiological needs (i.e. time for rest for average heavy works makes up 3% of the sum of main and auxiliary times),
- **group III** – component times described by an established period of the time (single-point distribution) depending on: e.g. the specificity of the working process, the technology of works' performance (i.e. the t_{pz} time makes up c.a. 4% of the working shift's time, which is c.a. 20 min.).

The **group I** times should be, as far as possible, examined empirically [9] and/or with simulation methods [10]. Times defined in **group II** are established based on determined standards, proportionally to the sum of times from **group I**. Times from **group III** can be examined and/or determined using the standards towards the time of the working shift.

In the proposed model, random time variables can be distributed [6, 2, 13, 14]:

a) normally $N(m, \sigma)$,
b) normally on both sides cut $N_{\alpha,\beta}(m, \sigma)$,
c) log-normally $LN(m, \sigma^2)$,
d) regularly in established range of value $R(t_1, t_2)$,
e) discreetly with a single-point $J(t_x)$.

Accuracy of the fit of the adopted theoretical distribution to the data obtained from measurements or simulations should be examined with a nonparametric tests [1, 12, 15, 16] such as: χ^2 test, *Kolmogorov-Smirnov* test or *Shapiro-Wilk* test.

In the probabilistic analysis of component times we appoint: the expected value $E\left(T_i^{\mathrm{I}}\right)$ of the sum of basic times from **group I**, a summary indicator $a' = \sum_{k=1}^{v} a_k$ proportional towards $E\left(T_i^{\mathrm{I}}\right)$ – (**group II**) and a sum of the component times $b' = \sum_{r=1}^{w} b_r$ (**group III**), where v and w mean number of component times in **groups II** and **III**.

Table 4

Estimating the execution time of simple working process in probabilistic approach (example)

Group	Components times [hrs]	probability level P_{uf} = **0,9772**			multiplicity of deviation $g = 2$		
		labour			**caterpillar dozer**		
		aver.	dev.	distribut.	aver.	dev.	distribut.
I	*tg*	4,083	0,310	normal	1,250	0,157	normal
	tp	1,117	0,257	normal	0,633	0,120	normal
	$E(Ti^x)$ =	6,333			2,437		
II		a_k	base	value	a_k	base	value
	to	0,030	6,333	0,156	0,020	2,437	0,038
	tf	0,015	6,333	0,078	0,015	2,437	0,028
	a'=	0,045			0,035		
III		b_r			b_r		
	tpz	0,500			0,583		
	txt	0,750			0,667		
	b'=	1,250			0,583		
		$(1 + a') * E(Ti) + b'$ =					
		$E(T_i^{x=1})$ = 7,868		$k_i^r = 2$	$E(T_i^{x=2})$ = 3,105		$k_{ij}^m = 1$
		$E(T_i)$ = max $\{E(T_i^x)\}$ = **3,934** [hrs]					

An estimation of the essential time for simple working process $E(T_i)$ performance, due to demand on working time established for each kind of resource, should be calculated in agreement with property (5) and formulas: (6) and (7) as showed in the table 4.

$$E\left(T_i^x\right) = \left(1 + a'^x\right) \cdot E\left(T_i^{1,x}\right) + b'^x, \tag{6}$$

$$E(T_i) = \max\left\{E\left(T_i^r\right), E\left(T_{i,j}^m\right)\right\} . \tag{7}$$

Indicator x in the equation (6) refers one by one to every kind of resource, performing the i-th process (i.e. labour $\{r\}$, and work of j-th type of machine {m, j}).

This complex working process is portrayed by probabilistic network models. Its characteristics are appointed by the set of component characteristics of simple processes and parameters of time dependencies between processes (order and offsets matrices – see table 3).

The characteristics of a complex process [1, 4, 7, 16] incorporate: the assumed type of distribution of random variables describing the execution time of complex processes (normal or log-normal distribution), while the expected value of execution time $E(T^c)$, standard deviation $\sigma(E(T^c))$, types of relations between the processes and potential offsets, probability level P_{uf}, which is acceptable for real data measurements (execution times of the process), and is at most equal to the adopted limit value $E(T^c_{\max})$.

$$E\left(T^c_{\max}\right) = E(T^c) + \Delta(T^c) \tag{8}$$

$$E(T^c) = \max\left\{\sum_{p=1}^{z^q}\left(E\left(T_p^q\right) + d_p^q\right)\right\} \tag{9}$$

$$\Delta(T^c) = g \cdot \sigma(E(T^c)) \tag{10}$$

$$\sigma(E(T^c)) = \sqrt{\sum_{p=1}^{z^q}\sigma^2\left(T_p^q\right)} \tag{11}$$

where:

- $\Delta(T^c)$ – time reserved in the network model, involving the accepted P_{uf}, probability level of meeting $E\left(T^c_{\max}\right)$ value, calculated from the standard normal table $N(0, 1)$ for the specific standard deviation of the execution time $E(T^c)$,
- $E\left(T_p^q\right)$ – expected value of the execution time of p-th process on the q-th path,
- g – multiplicity of the standard deviation assuming P_{uf} probability level,
- $\sigma^2\left(T_p^q\right)$ – variance of the p-th process on the q-th path of processes.

Value $E\left(T^c_{\max}\right)$ estimated according to relations (8)÷(11) with the probability level P_{uf} (usually 0.99865 for g = 3) won't be overestimated. This value meets the condition: $P\left(T^c \le T^c_{\max}\right) = P_{uf}$.

4. Conclusions

Working processes' modelling in the planning aspect [8], in particular when estimating the execution time of working processes, which is the subject of this paper, requires a good knowledge of the processes' nature and specific parameters.

The most important issues, which provide the utilitarian character of the models introduced, are: high cost and high labour demand necessary to run multiple experiments "in-situ", in order to obtain credible data for planning [10], cost control or allocation of equipment units [8, 11] etc. Moreover, the changeability of parameters and conditions of working process performance – is, (apart from when performed in the laboratory) natural, however, hampers the collection of appropriate information.

Process realization modelling contributes to a better understanding of significant parameters and relations appearing in process performance. One should notice, that analysing the nature of process' realization and building its model, even the simplest one, is one of the first steps in overcoming the problems which can appear in process realization.

An appropriate and credible model, mapping the examined problem, can be one of many tools applicable to limiting recalled costs and workloads for examinations and observations. By having a model at ones disposal, it is possible e.g. to apply simulation methods to multiply the data obtained in examinations on so-called "small samples".

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CONSTRUCTION SCHEDULE OF WORKS AS COMBINATORIAL OPTIMIZATION PROBLEM

HARMONOGRAMOWANIE PRZEDSIĘWZIĘCIA JAKO ZAGADNIENIE KOMBINATORYCZNE

Abstract

Construction schedule optimization generally deals with the identification of the feasible sequence of activities and allocation of modes that provide the most efficient construction performance according to the assumed evaluation criteria. The specific technological order of activities results in the numerous feasible sequences of activities and availability of alternative modes results in the numerous mode combinations. Construction scheduling becomes, therefore, a difficult combinatorial problem that is usually underestimated by the planners. This is the main reason for obtaining schedules that result in construction implementation lasting too long and costing too much. It is, nevertheless, possible to identify the construction schedules that provide excellent results. A simple, simulation-based approach is presented in this paper. Its originality results from nature of applied model and a way the calculations are made. The effectiveness of the approach is illustrated by means of a sample analysis based on data provided by [1]. The approach also proved useful for solving scheduling problems in engineering practice.

Keywords: construction, schedule, optimization, decision, support, activity sequence, mode, allocation, combinatorial problem

Streszczenie

Optymalizacja harmonogramu przedsięwzięcia polega na doborze takiej dopuszczalnej kolejności wykonywania prac oraz przydzieleniu takich sposobów wykonania operacjom, które zapewnią najlepsze możliwe, zgodnie z przyjętymi kryteriami oceny harmonogramu, wykonanie przedsięwzięcia. Z technologicznego porządku prac wynika zwykle duża, a często nawet astronomiczna liczba ich dopuszczalnych uporządkowań. Złożoność procesu harmonogramowania dodatkowo podwyższa dostępność alternatywnych sposobów wykonania prac. Harmonogramowanie przedsięwzięć stanowi więc w istocie trudne, a przy tym niedoceniane przez planistów, zagadnienie kombinatoryczne. W rezultacie otrzymujemy harmonogramy odpowiadające nadmiernie czaso- i kosztochłonnej realizacji przedsięwzięcia. Przy odrobinie wysiłku można jednak uzyskać harmonogramy, które odpowiadają krótkiej i taniej realizacji przedsięwzięcia. Temu celowi służy również autorskie narzędzie symulacyjne przedstawione w pracy. Stanowi ono oryginalne podejście zarówno w zakresie modelu, jak i sposobu wykonywania obliczeń, do których dane zaczerpnięto z pracy [1]. Wyniki pracy zostały także zastosowane w praktyce inżynierskiej.

Słowa kluczowe: przedsięwzięcie budowlane, harmonogram, optymalizacja, decyzja, wspomaganie, kolejność prac, sposób wykonania, przydział, zagadnienie kombinatoryczne

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1. Introduction

Construction projects deal with the execution of many different activities associated with the various building work being carried out. Sound project implementation requires the careful preparation. Construction schedules are applied in this regard. Construction scheduling deals with three primary decisions related to the choice of an appropriate feasible sequence of activities, the project start date and the allocation of available modes of construction activities. A specific schedule for a construction project results from a set of such decisions. The effects of these decisions are evaluated by means of schedule evaluation criteria. Project makespan T and total cost C are usually applied in this regard.

Note, that the technological order of activities is applied in numerous feasible sequences of activities, however, the availability of alternative modes for activities cause such scheduling to be problematic. Construction scheduling can then become a severe combinatorial optimization problem. The problem is hard to solve in acceptable time even in the case of construction projects that consist of average or small numbers of activities. Due to this, we are usually forced to rely solely on approximation schemes while scheduling real construction projects. Note, that mainly heuristic and metaheuristic approaches are applied in this regard [2]. The application of such approaches brings advantages in the case of the complex projects. This is because efficient "evolutionary" mechanisms allows for feasible solutions to the scheduling problem. This approach also deals with several drawbacks. At first, they comprise a kind of a black box. This fact discourages the conscious planners from using such approaches which risk losing control over the accuracy of analysis results. Secondly, the successful application of this approach relies on conducting time-consuming introductory numerical experiments. These experiments provide appropriate values vital to those parameters which influence the performance of the approaches.

The simple, yet powerful approach that addresses the drawbacks of the more advanced optimization methods, is presented in this paper. The approach is based on simple numerical simulation experiments [3] and provides near Pareto-efficient schedule for a construction project in terms of simultaneous minimization of make span and total cost.

2. Schedule optimization model

The following assumptions are made while structuring the model. A construction project consist of m activities, denoted by o(1), o(2)...o(m). The activities represent the consecutive construction works. There are o_i alternative modes available for the activity o(i), where $i = 1, 2...m$. It is assumed that each activity is executed by means of a single selected mode only. Each alternative mode requires the application of a specific resource – manpower, equipment and building materials. Building materials are considered to be a non-renewable resource because they undergo continuous exhaustion in the course of the construction process. Note, that a given set of structural and material solutions is considered. The same building materials are then applied while executing a given construction activity, regardless of the selected mode. It is also assumed that the necessary building materials are always available when required.

Manpower and equipment are the renewable resources because they become available again as soon as an activity ends. It is assumed that the renewable resources are available in sets corresponding with different modes available for the activities. Such sets are called the technical means sets (TMSs) and are denoted by z(1), z(2)...z(Z), where Z is the number of available TMSs. The number of available items for z(k) is expressed by $l(k)$. Note, that peculiarity of construction processes results in the possibility of using the same renewable resources for executing different activities. A TMS may also consist of other, less complex TMS. If an item of a given TMS is utilised while executing a construction activity then it is unavailable for other activities at the same time. This assumption is important for the cases when different activities are concurrently executed and they may use the same TMS. The resource-related conflicts then occur due to the limited availability of the required TMS.

The acyclic, asymmetric and joined digraph $G(V, E)$ is applied to represent a feasible sequence of construction activities. In this paper this sequence is known as a project structure. Digraph vertices V express project events labelled by 0, 1...n, while digraph arcs E express the activities This paper describes the technological order of activities as the precedence structure. It is also represented by the acyclic, asymmetric and joined digraph $\Gamma(V, E)$. The digraph arcs correspond with construction activities while the digraph arcs express the relations of direct precedence for the activities. The sample precedence structure for a sample 10-activity project is presented in Fig. 1, while a corresponding sample project structure is presented in Fig. 2.

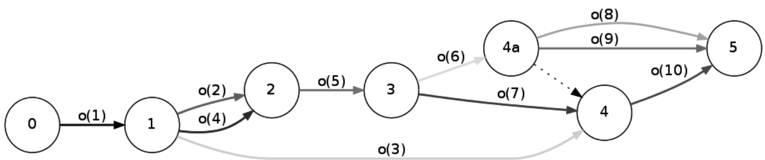

Fig. 1. A precedence structure for a sample construction project

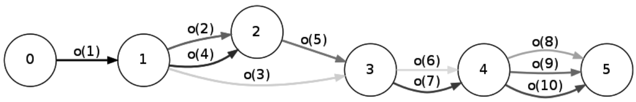

Fig. 2. A feasible project structure for a sample construction project

The model that corresponds with the presented assumptions is given in Eqns. (1–6). The meaning of the applied symbols is expressed immediately below.

$$\min_{G \in \bar{G}} \left\{ \min_{\mathbf{x}} F = w_1 \frac{T_n(G, \mathbf{x}, \boldsymbol{\tau}, T_0) - T_0}{\bar{T}} + w_2 \frac{C(G, \mathbf{x}, \boldsymbol{\kappa})}{\bar{C}} \right\}, \quad (1)$$

$$\underset{i \in \{1, \dots m\}}{\forall} \sum_{j=1}^{o_i} x_{ij} = 1, \quad \underset{i \in \{1, \dots m\}}{\forall} \; \underset{j \in \{1, \dots o_i\}}{\forall} \; x_{ij} \in \{0, 1\}, \quad (2)$$

$$T_0 = 0, \quad \underset{k \in \{1, 2 \dots n\}}{\forall} \; \underset{i \in \Gamma_k^-}{\forall} \; T_k\left(G, \mathbf{x}, \boldsymbol{\tau}, T_0\right) \geq t_i^{(s)}\left(G, \mathbf{x}, \boldsymbol{\tau}, T_0\right) + \sum_{j=1}^{o_i} x_{ij} \tau_{ij} \quad (3)$$

$$\underset{k\in\{1,2\ldots n\}}{\forall} T_k \geq T_{k-1}, \tag{4}$$

$$C(G,\mathbf{x},\boldsymbol{\kappa}) = \sum_{i=1}^{m}\sum_{j=1}^{o_i} x_{ij}\kappa_{ij}, \tag{5}$$

$$\underset{k\in\Xi(G)}{\forall} \sum_{(i,j)\in\zeta^{(k)}} x_{ij} \leq L_{l(k)}. \tag{6}$$

The goal function presented by Eqn. (1) uses the simultaneous minimization of T and C. Note, that to make T and C commensurable, they are divided by the reference values $\overline{T}$ and $\overline{C}$, respectively. Normalized weights w_1 and w_2 express the relative importance of T and C. Note that the goal function provides the appropriate project structure G out of the set of all feasible project structures $\overline{G}$. The corresponding allocation of available modes to activities is also identified. The selected modes are represented by the binary decision variables x_{ij}, where: $i = 1, 2\ldots m$ and $j = 1, 2\ldots o_i$. The variables comprise the matrix of decision values $\mathbf{x}$.

The makespan is expressed by means of the difference between time of terminal project event occurrence T_n and the assumed time of starting project event occurrence T_0. It depends on the assumed project structure G, the selected modes x and the regular duration of activities corresponding with the available modes. Note, that the application of the j-th mode applicable in the case of the activity o(i) results in the regular activity duration τ_{ij}. Regular activity durations corresponding with all modes comprise the matrix $\boldsymbol{\tau}$. The total project cost C depends on the applied project structure G, and the chosen modes $\mathbf{x}$. Regular cost for available modes is denoted by κ_{ij}. Let us observe that matrices $\mathbf{x}$, $\boldsymbol{\tau}$ and $\boldsymbol{\kappa}$ have the same sizes.

Eqn. (2) assures that a single application mode is applied in the case of each activity and Eqn. (3) enforces the natural occurrence of the consecutive project events: T_k, where $k = 1, 2\ldots n$. Time of the occurrence of project events depends on the assumed project structure G selected modes $\mathbf{x}$, the regular duration of the activities $\boldsymbol{\kappa}$, and the assumed time of occurrence of the starting project event T_0. Note, that Γ_k^- expresses the set of activities terminated by the k-th project event, where: $k = 1, 2...n.$, and $t_i^{(s)}$ is the time of the occurrence of the starting event for the activity o(i).

The assumed sequence of the activities G is enforced by Eqn. (4). The following sum: $\sum_{j=1}^{o_i} x_{ij}\kappa_{ij}$ denotes the actual cost of the execution of the activity o(i), where: $i = 1, 2...m$. The total project cost is given in Eqn. (5). The actual duration of the activity o(i) is equal to: $\sum_{j=1}^{o_i} x_{ij}\tau_{ij}$.

The Eqn. (6) deals with the possible competition for renewable resources between different activities. It is assumed that the k-th conflict deals with a specific TMS. The number of available items of that TMS is denoted by $L_{l(k)}$. Note, that the number of possible conflicts is denoted by Ξ and depends on the assumed project structure G. The set of modes invoλved in the κ-th conflict, where: $k = 1, 2...$ Ξ is denoted by $\zeta^{(k)}$. The involved modes are described by the pairs of indices (i, j), where i and j express the number for the activity and the mode, respectively ($i = 1, 2...m$; $j = 1, 2...o_i$).

Note, that the considered scheduling problem is a kind of the Multi-mode Resource Constrained Project Scheduling Problem (RCPSP) [5] and is formulated as the mixed integer linear programme (MILP). Both the exact and the approximate [2] approaches can be applied to solve it. For example, the following exact approaches are applicable in this regard: Mixed Integer programming, Dynamic Programming Constraint Programming, Branch and Bound, and Benders Decomposition. The approaches mentioned provide exact optimization results but become less efficient in the case of the construction projects consisting of the numerous activities.

3. The applied approach

The applied approach addresses the drawbacks of the exact and approximate methods. It is based on the decomposition of the original problem into 2 levels:

1. The upper level deals which provides the appropriate feasible project structure G^* and the corresponding selection of modes $\mathbf{x}^*$ – note, that they define the near Pareto-efficient schedule.
1. The lower level deals with the (lower level) tasks – the MILP problems, obtained for the representative project structures $G \in \overline{G}$ and the following goal function which replaces the goal function given in Eqn. (1):

$$\min_{\mathbf{x}} F = w_1 \frac{T_n(G, \mathbf{x}, \boldsymbol{\tau}, T_0) - T_0}{\overline{T}} + w_2 \frac{C(G, \mathbf{x}, \boldsymbol{\tau})}{\overline{C}}. \tag{7}$$

Note, that the solution of the upper level problem is identical with the solution of the original problem given in Eqns. (1–6). The simple ranking of the locally Pareto-efficient solutions corresponding with the lower level tasks is enough in this regard. The ranking corresponds with the decreasing values of the goal function given in Eqn. (7).

The simulations are applied to generate the representative project structures G. The redundant representation of all feasible structures for a project is applied in this regard [3]. The representation is expressed by the acyclic, asymmetric and joined digraph $\overline{G}(\overline{V}, \overline{E})$. It consists of the vertices mapping all possible project events from the starting event labelled 0 to the latest possible terminating project event labelled m. The digraph arcs correspond with all alternative locations of the activities in feasible project structures. Note, that the choice of a single arc for each activity is enough to generate a feasible project structure.

Two different proposed approaches are finally applied [5]. They differ in the methods applied to solve a lower level problem. The first detailed approach is called MC-LP and combines random generation of representative project structures with linear programming to solve the lower level tasks. The second detailed approach, called MC-MC, applies the random generation for both the representative project structures G and the selection of modes $\mathbf{x}$. The both approaches complement each other. MC-LP is capable of providing more accurate results, while MC-MC is capable of performing better in the case of projects with a considerable number of activities.

Note, that the definition of the number of the generated feasible structures N' is required in order to apply the MC-LP and MC-MC approaches. The number of generated allocations of modes to activities (N'') should be defined to make the MC-MC application possible. The simple introductory simulation experiments are utilised to provide the required values for N' and N''. The introductory experiment for estimating N' deals with a number of lower level tasks solved by the means of the MC-LP approach while the introductory experiment for the MC-MC deals with a lower level task obtained for a single project structure. The following Formulae are applied in this regard:

$$N' \geq \frac{Z^2_{\frac{\alpha}{2}}\,\sigma(F)^2}{d'^2}, \quad N'' \geq \frac{Z^2_{\frac{\alpha}{2}}\,\sigma(F)^2}{d''^2} \tag{8}$$

where: $Z_{\frac{\alpha}{2}}$ denotes the parameter corresponding with the assumed possibility distribution and the confidence level α, while generating project structures (N') or mode allocations (N''), $\sigma(F)$ is the standard deviation in F values obtained during an introductory experiment and d', d'' denote the assumed absolute accuracy level while generating the feasible project structures and the mode allocations, respectively.

Note, that minimal goal function values F' and F'' provided by the introductory experiments can be applied to express the relative accuracy values ε', ε'':

$$\varepsilon' = \frac{d'}{F'}, \quad \varepsilon'' = \frac{d''}{F''} \tag{9}$$

The Eqns. (8, 9) make it then possible to obtain the relations ε' (N') and ε'' (N''). Note, that the MC-MC approach deals with the double simulation experiment, however. The overall relative accuracy ε thus depends on both N' **and** N':

$$\varepsilon = (1+\varepsilon')(1+\varepsilon'') - 1\,. \tag{10}$$

The appropriate combination of N' **and** N'' values can be then estimated for the required level on the basis of a minimal required computational effort expressed by product: $N'\,N''$.

4. The sample analysis

A sample construction project deals with a public garage building [1]. The project consists of 10 activities. Available modes for the activities depend on 31 different TMSs. The precedence structure for the sample project is presented in Fig. 1. The Pareto-efficient schedule is known for the sample project. It results from the exhaustive review of all, almost 10,000 feasible project schedules, and solving the related lower level tasks by the means of the linear programming: $F^* = 0.795$, $T^* = 194$ days and $C^* = 13{,}170{,}000$ PLN. It was obtained while assuming the following parameter values: $w_1 = 0.3$, $w_2 = 0.7$, $\overline{T} = 354$ days and $\overline{C} = 14{,}620{,}000$ PLN. Knowledge about the Pareto-efficient solution is applied to assess the real accuracy of the presented approach.

Uniform possibility distribution is applied while generating feasible project structures and the mode allocations. The introductory experiments deal with the generation of 20 feasible project structures and 20 mode allocations (MC-MC). These results are presented in Fig. 3. The experiments took the fraction of a second of mediocre CPU time. It proves that 13 generated project structures allow for breaking the 1% accuracy ε' limit, and 11 mode allocations should be enough to break the same limit in the case of the ε'' accuracy. Note also, that the Pareto-efficient schedule is identified already after the generation of two project structures only while using the MC-LP approach.

It proves that breaking the 1% ε accuracy level requires at least 150 feasible project structures and 25 mode allocations in the case of MC-MC approach.

A project structure corresponding with the obtained near Pareto-efficient schedule is presented in Fig. 2. The schedule corresponds with the goal function value $F = 0.802$ (+0.9% compared with the Pareto-efficient schedule), $T = 199$ days (+2.4%) and $C = 13.228,000$ PLN. The results are obtained in less than 33 seconds of mediocre CPU time.

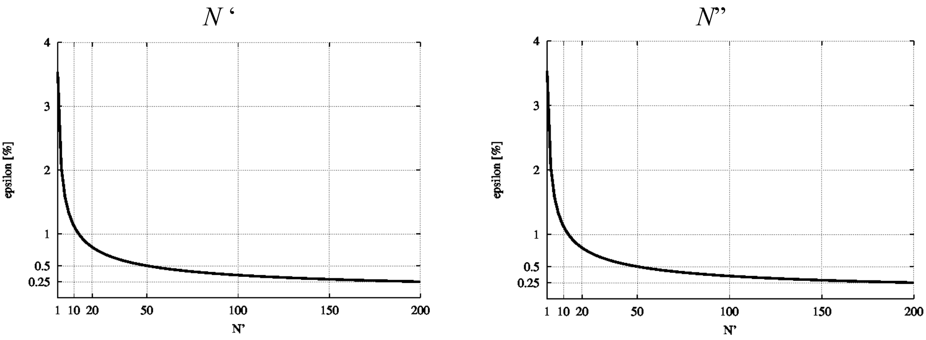

Fig. 3. Introductory analysis results for a sample project

5. Conclusions

The results obtained for the sample construction project confirm usability of the applied approach for the rapid identification of near Pareto-efficient schedules. The schedules provided by the approach are at most slightly worse than the Pareto-efficient schedule. Application of linear programming techniques and Monte Carlo simulations makes the approach reliable both in the case of projects consisting of smaller number of activities and in the case of the more complex projects with a considerable number of activities. MC-MC proves also useful while solving non-linear scheduling problems dealing with the influence of the surrounding environment.

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IDENTIFCATION OF WEATHER INSENSITIVE TO CONSTRUCTION SCHEDULES

IDENTYFIKACJA HARMONOGRAMU BUDOWLANEGO NIEWRAŻLIWEGO NA POGODĘ

A b s t r a c t

Construction scheduling deals with the decisions which can affect the feasible sequence of construction activities, the selection of alternative execution modes for the activities and the positioning of the construction in time. Effects of these decisions can be evaluated by means of specific schedule evaluation criteria. However, the peculiarity of construction in civil engineering causes that the real effects of the construction also depend on the influence of the surrounding environment. For example, construction processes are sensitive to adverse weather. Poor weather influences the actual performance of construction activities. The performance of the activities influences the performance of the whole construction project. Thus, the performance of whole construction project is also influenced by bad weather. Considering the influence of adverse weather is therefore indispensable when preparing a reliable construction schedule. Note, that the effects of poor weather on actual construction performance can be limited by the careful choice of the activity sequence, construction time lines, and the execution modes for various activities. The approach is presented, in this paper therefore provides the appropriate sequence of construction activities, related starting date and the allocation of execution modes to the activities in order to make construction schedule less sensitive to inclement weather.

Keywords: construction, schedule, optimization, activity, sequence, execution mode, allocation, inclement weather, sensitivity

S t r e s z c z e n i e

Harmonogramowanie przedsięwzięcia polega na wyborze właściwej kolejności wykonania prac budowlanych, sposobów wykonania poszczególnych prac oraz umiejscowienia realizacji przedsięwzięcia w czasie. Do oceny efektów tych decyzji są wykorzystywane odpowiednie kryteria, np. planowany czas i koszt wykonania przedsięwzięcia. Zauważmy również, że na skutek specyfiki produkcji budowlanej rzeczywiste rezultaty wykonania przedsięwzięcia zależą od oddziaływania otoczenia. Typowym przykładem niekorzystnego oddziaływania otoczenia są zmienne warunki pogodowe. Wiele rodzajów prac budowlanych (roboty ziemne, betonowe, montażowe itp.) jest wrażliwych na oddziaływanie warunków pogodowych. Niekorzystne warunki wpływają więc na efekty realizacji prac, które wpływają z kolei na rezultaty realizacji całego przedsięwzięcia. Rezultaty te zależą więc również od warunków pogodowych. W trakcie harmonogramowania przedsięwzięcia jest konieczne uwzględnianie niekorzystnego wpływu pogody na efekty realizacji prac i przedsięwzięcia. Zauważmy przy tym, że wpływ niekorzystnej pogody można ograniczać już na etapie harmonogramowania przedsięwzięcia, dobierając właściwą kolejność wykonania prac, odpowiednie sposoby ich wykonania oraz czas rozpoczęcia przedsięwzięcia. W pracy przedstawiono podejście symulacyjne ułatwiające określenie właściwej kolejności realizacji prac i skojarzonej z nią daty rozpoczęcia przedsięwzięcia oraz odpowiedniego przydziału sposobów wykonania operacjom w warunkach niekorzystnego oddziaływania pogody.

Słowa kluczowe: przedsięwzięcie, harmonogram. optymalizacja, prace budowlane, kolejność, sposób wykonania, przydział, niekorzystna pogoda, wrażliwość

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1. Introduction

A construction schedule provides the necessary means for sound construction project implementation. Scheduling deals with the regular decisions that pertain to the selection of the appropriate sequence and execution modes for construction activities, and accurate project time lines. The peculiarity of certain construction processes, however, results in the construction being influenced by conditions caused by the surrounding environment. These possible influences should therefore be included, when preparing the schedule for a construction project.

Many construction processes are weather sensitive. For example, earthworks, concrete-based and assembly processes which are especially sensitive to poor weather. The influence of adverse weather should therefore be properly addressed while scheduling a construction project, in order to provide necessary means for exact and inexpensive project implementation.

The effects of dverse weather and the influence these have on construction processes is a well recognized phenomenon. The optimization of construction projects while considering the possible effects of bad weather is dealt with in the available literature [1–7]. These examples, however, prove that current approaches do not address all regular scheduling decisions. The numerical approach is therefore presented in this paper, which can help to make regular scheduling decisions, while including the inclement weather influence. The approach applies Monte Carlo simulations.

2. The computational model

Let us assume that a construction project deals with the construction works that are represented by m activities: o(1), o(2)…o(m). There are o_i alternative execution modes available for the activity o(i), where: $i = 1, 2 \ldots m$. A single execution mode only can be applied for the execution of an activity. Selection of the j-th execution mode for the execution of the activity o(i) is indicated by the unitary value of the decision variable $x_{ij} = 1$, where: $i = 1, 2 \ldots m$ and $j = 1, 2 \ldots o_i$. The choice of the j-th execution mode results in the regular duration τ_{ij} and cost κ_{ij} for the activity o(i). Decision variables x_{ij} and the regular duration and cost values for all available execution modes constitute the m by $\max_i \{o_i\}$ matrices $\mathbf{x}$, $\boldsymbol{\tau}$, $\boldsymbol{\kappa}$, respectively ($i = 1, 2 \ldots m$).

Construction activities should therefore be executed in a given technological order. In this paper the order is known as the precedence structure. The acyclic, asymmetric and joined digraph representation $\Gamma(V, E)$ is usually applied to express the structure. The digraph arcs E express the activities and digraph vertices V denote the direct precedence relations between the activities. In this paper, the actual feasible sequence of activities are known as project structure, also described by the means of the acyclic, asymmetric and joined digraph $G(V, E)$. This time, however, the vertices represent project events labeled 0, 1…n, where n is at most equal to m. Note, that there are usually a lot of feasible project structures available. The precedence structure and a corresponding feasible project structure are presented in Fig. 1.

The application of execution modes require the following necessary resources – manpower, building equipment and materials. Manpower and equipment are considered as renewable resources because they become available immediately after the completion of an activity, that used them recently. Building materials comprise the non-renewable resources due to the fact that they undergo the continuous consumption during project implementation. Let us observe that fixed construction and material solutions are considered while applying the alternative modes for the execution of activities. It is therefore assumed that all necessary building materials will be available when required.

Note, that execution modes can be expressed by the required renewable resources. It is advantageous, therefore, to consider the availability of the resources in sets. The notion of a technical means set (TMS) is applied in this regard. A given TMS can depend on a less complex TMS. The application of an item of a given TMS makes an item of a component TMS unavailable at the same time, and vice versa.

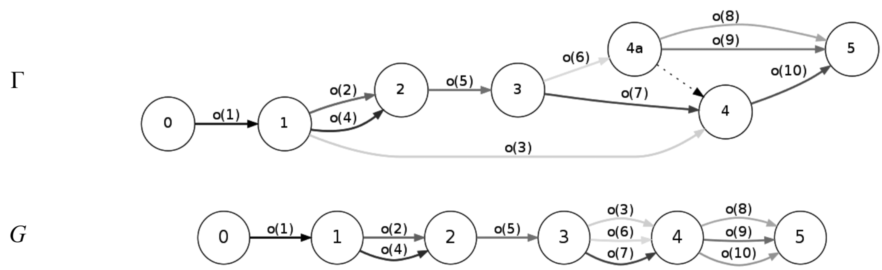


Fig. 1. The sample precedence structure and a corresponding project structure

The peculiarity of construction processes often results in the possibility of using the same renewable resources for the execution of different activities. Necessary resources are usually available in the limited quantities resulting in activities which are executed concurrently competing for common resources. Such the competition deals with the distinct execution modes.

Each possible conflict deals with a specific TMS. The available number of items for that TMS is equal to $L_{l(k)}$. The number of possible conflicts is denoted by Ξ. Note that the number depends on the applied project structure: Ξ(G). The set of execution modes involved in the k-th possible conflict, where k = 1, 2… Ξ, is denoted by $\zeta^{(k)}$. The involved execution modes are expressed by the ordered pairs (i, j), where: i is number of the activity and j denotes the execution mode.

The influence of the weather inclement is expressed by the means of the standard climatic year and the general function of the sensitivity to adverse weather. The standard 365-day-long climatic year does not include February, the 29th. The discrete and binary general function of the sensitivity $\Omega(i, j, k)$ deals with a given execution mode (i, j). It indicates the days of the standard year (k = 1, 2…365) that allow the execution of the activity o(i) while applying the j-th execution mode. The function $\Omega(i, j, k)$ results from the individual sensitivity of an execution mode to inclement weather and the representative weather conditions for the standard climatic year's days [8]. The official recommendations [9] are applied to assess the adverse weather sensitivity. The average hourly data provided by Polish Ministry for Infrastructure and Regional Development (available at the URL: http://www.mir.gov.pl/budownictwo/rynek_budowlany_i_technika/efektywnosc_energetyczna_budynkow/typowe_lata_meteorologiczne/strony/start.aspx) are utilized to define the representative weather data for the standard climatic year's days. The data also corresponds with the location of the construction works. The sample standard climatic year-long profile for a sample general function of the sensitivity is presented in Fig. 2. $\mathbf{\Omega}$ is applied to denote the complete set of general functions of the sensitivity to adverse weather.

It is assumed that an entire working shift is utilized to do construction works. The shift begins at 7 a.m., CET and ends at 5 p.m. The execution of an activity is halted for a whole day if the unacceptable conditions appear during that day. Note, that the actual delay in the execution of the activity results in the additional, adverse weather induced cost. The cost deals with the constant expenditure related to the utilized renewable resources. The induced cost for the execution mode (i, j) is denoted by $\Delta\tau_{ij}$ and correspond with a whole working shift. The values for all available execution modes are given in the matrix $\Delta\boldsymbol{\tau}$. The matrix is size-compatible with other data matrices: $\mathbf{x}$, $\boldsymbol{\tau}$, $\boldsymbol{\kappa}$.

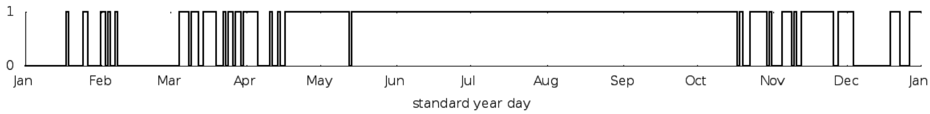


Fig. 2. The standard climatic year-long profile for the sample function $\Omega(i, j, k)$

The computational model is proposed to identify a near Pareto-efficient schedule, while including the influence of poor weather. The appropriate project structure G^*, the corresponding starting date θ_0^*, and allocation of execution modes to activities $\mathbf{x}^*$ are applied in this regard. The model is given in Eqns. (1–6):

$$\min_{G\in\bar{G}}\left\{\min_{\theta_0\in\bar{\theta}}\left\{\min_{\mathbf{x}} F = w_1\frac{T_n(G,\mathbf{x},\boldsymbol{\tau},\mathbf{\Omega},\theta_0)-\theta_0}{\bar{T}}+w_2\frac{C\left(G,\mathbf{x},\boldsymbol{\kappa},\mathbf{\Omega},\Delta\boldsymbol{\kappa},\theta_0\right)}{\bar{C}}\right\}\right\}, \tag{1}$$

$$\underset{i\in\{1,\ldots m\}}{\forall}\ \sum_{j=1}^{o_i} x_{ij}=1,\quad \underset{i\in\{1,\ldots m\}}{\forall}\ \underset{j\in\{1,\ldots o_i\}}{\forall}\ x_{ij}\in\{0,1\}, \tag{2}$$

$$T_0=\theta_0, \tag{3}$$

$$\underset{k\in\{1,2\ldots n\}}{\forall}\ \underset{i\in\Gamma_k^-}{\forall}\ T_k\left(G,\mathbf{x},\boldsymbol{\tau},\mathbf{\Omega},\theta_0\right)\geq t_i^{(s)}\left(G,\mathbf{x},\boldsymbol{\tau},\mathbf{\Omega},\theta_0\right)+\sum_{j=1}^{o_i}x_{ij}\left\{\tau_{ij}+\Delta\tau_{ij}\left[\bar{\theta}(\theta),\mathbf{\Omega}\right]\right\}, \tag{4}$$

$$\underset{k\in\{1,2\ldots n\}}{\forall}\ T_k\geq T_{k-1}, \tag{5}$$

$$\underset{k\in\Xi(G)}{\forall}\ \sum_{(i,j)\in\zeta^{(k)}} x_{ij}\leq L_{l(k)}. \tag{6}$$

The goal function that is given in Eqn. (1) deals with the concurrent minimization of project makespan T and total cost C. Note, that the makespan is actually expressed by the difference between the terminal project event occurrence time T_n and the assumed starting date θ_0. The time of the terminal project event occurrence depends on the assumed project structure, the selection of execution modes, the regular activity duration for the execution modes, the general functions of the sensitivity to adverse weather, and the assumed starting date. The total cost of the project also depends on the same entities as well as regular additional cost induced by the delays in the execution of the activities. Project makespan and total cost are brought to the state of the commensurability by the means of the division by the reference values $\bar{T}$ and $\bar{C}$, respectively. Normalized weight values w_1 and w_2 express the relative influence of T and C, respectively.

Note, that the goal function consists of 3 levels. The top level is devoted to the identification of the appropriate project structure G^*, the intermediate level deals with the estimation of the appropriate starting date θ_0^* that corresponds with G^*, and the bottommost level pertains to the appropriate selection of the execution modes $\mathbf{x}^*$.

Eqn.(2) enforces application of a single execution mode only for each activity. Eqn. (3) deals with the definition of the starting project event date.

Formula (4) allows for determining the occurrence dates of consecutive project events T_1, T_2 ...T_n. Symbol Γ_k^- denotes set of activities that finish at the k-th project event, where: $k = 1, 2\ldots n$, and $t_i^{(s)}$ is the time of the occurrence of the starting event for the activity o(i). Note, that both T_k and $t_i^{(s)}$ depend on the assumed project structure, the selected execution modes, the regular duration for the execution modes, the general functions of sensitivity to adverse weather, and the assumed starting date. The second component of the right side of inequality presented in Eqn. (4) expresses the total duration of the activity o(i). Both the regular duration and the induced delays are considered in this regard. The actual delay in the activity o(i) execution is denoted by $\Delta\tau_{ij}$. It depends on the general functions of the sensitivity to adverse weather and the function that maps actual date $\bar{\theta}$ (where: $\bar{\theta} = \theta_0, \theta_1 ... T_n$) onto the corresponding standard climatic year's day θ.

Eqn. (5) assures that the project events occur in the assumed order, while Eqn. (6) deals with the competition between different activities for limited resources.

Let us observe, that the model given in Eqns. (1–6) seems to be mixed linear programming model but it is non-linear, in fact. The non-linearity of the model results from the influence of adverse weather.

3. The applied solution approach

The considered problem is a combinatorial problem because of the numerous feasible project structures and multiple execution modes available for the activities. The non-linearity of the considered problem makes it even more difficult to solve. The parametric decomposition of the original problem is proposed, therefore, to make it easier to solve. The multi level nature of the goal function given in Eqn. (1) is utilized in this regard. The original problem is divided into 3 levels:

1. The upper level deals with the identification of the project structure G^*;
2. The intermediate level is devoted to the estimation of the starting date θ_0^*;
3. The lower level pertains to the selection of the execution modes $\mathbf{x}^*$.
4. Note, that the lower level deals with the tasks that correspond with the representative feasible project structures G, selected out of the set of all feasible project structures $\bar{G}$, and the starting project dates $\theta_0 = 1, 2\ldots365$. The tasks are based on the goal function:

$$\min_{\mathbf{x}} F = w_1 \frac{T_n(G, \mathbf{x}, \boldsymbol{\tau}, \boldsymbol{\Omega}, \theta_0) - \theta_0}{\bar{T}} + w_2 \frac{C(G, \mathbf{x}, \boldsymbol{\kappa}, \boldsymbol{\Omega}, \Delta\boldsymbol{\kappa}, \theta_0)}{\bar{C}}, \tag{7}$$

and the constraints presented in Eqns. (2–6). A locally Pareto-efficient schedule, is therefore obtained for each lower level task [10]. The solutions for the intermediate level tasks and upper level task are provided by the ranking of locally Pareto-efficient schedules, obtained for lower level tasks. Decreasing order of goal function values is applied to create the ranking. Let us also note that, the upper level solution provides a near Pareto-efficient schedule, which is identical with the solution of the original problem.

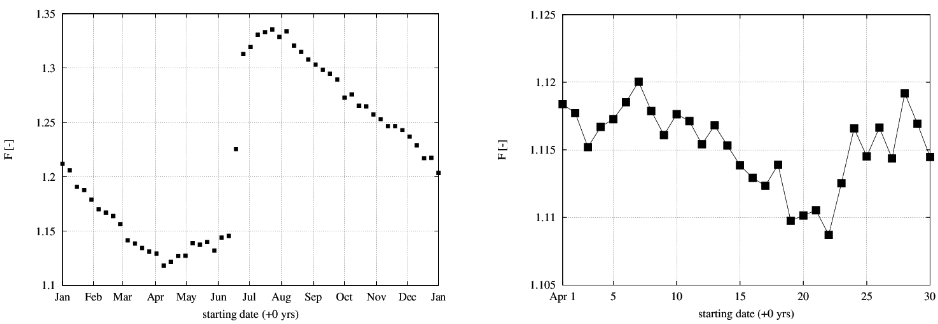
The combinatorial and non-linear nature of the considered problem result in the selection of the Monte Carlo-based approach to solve it. Therefore, the MC-MC approach [10, 12] is applied in this regard.

4. Sample analysis

A sample construction project is applied. The project deals with the erection of the public facility [11]. The project consist of 10 activities. Thirty one different TMSs provide the necessary means for the execution of the activities. The following parameter values are applied in the goal function given in Eqn. (1): w_1 = 0.3, w_2 = 0.7, $\bar{T} = 354$ days and $\bar{C} = 14,620,000$ PLN. The precedence structure for the project is presented in Fig. 1.

The results obtained for the introductory simulation experiment involving the random generation of 20 project structures and 20 execution mode allocations for each structure, and the 53 starting dates are presented in Fig. 3. The calculations took 9 minutes and 13 seconds of mediocre CPU time. The results reveal that the best starting dates are in April. Analysis of the estimated accuracy and effort [12] suggests the generation of at least 250 project structures and 150 execution mode allocations **x** while searching for the near Pareto-efficient schedules and assuming the 1% overall accuracy level.

Each date in April is utilized as the starting date for the project θ_0 during the final analysis. The analysis results are presented in Fig. 3. The identified near Pareto-efficient schedule corresponds with the starting date of April, the 22nd and the terminal date of the September, the 12th in the following year. The schedule results in the project implementation that lasts for 509 days and costs 14,147,000 PLN. The goal function value is: $F^* = 1.109$. The corresponding project structure is presented in Fig. 2. The calculations took 15 hours 40 minutes and 26 seconds.



The introductory results The final results

Fig. 3. The obtained results

5. Conclusions

The results presented prove the efficiency of the approach presented, which is capable of providing a near Pareto-efficient schedule for a construction project in a reasonable time. Application of Monte Carlo simulations makes this approach suitable for the analysis of construction projects which consist of different numbers of activities. The most important advantages deal with simplicity, the capability of controlling the actual accuracy of the computations, and a possibility of conducting the multi-level analysis devoted to the step-wise approximation of the most advantageous near Pareto-efficient schedule. The approach is thus worth further development in the future.

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EV WITH DURATION FORECASTING. CASE STUDY

PRZYKŁAD ZASTOSOWANIA EV WRAZ Z PROGNOZĄ TERMINU KOŃCOWEGO

A b s t r a c t

This paper presents development of the earned value concept regarding forecasting project duration time. On the basis of the calculations carried out for an implemented investment project, consisting of development of the sanitary sewage and municipal water supply system, individual methods and their assumptions were presented and discussed.

Keywords: EV, duration forecasting, ES, PV, ED

S t r e s z c z e n i e

W artykule przedstawione zostało rozwinięcie wartości wypracowanej w aspekcie prognozowania terminu końcowego realizacji. Na podstawie obliczeń przeprowadzonych dla zrealizowanej inwestycji obejmującej swoim zakresem rozbudowę kanalizacji sanitarnej i wodociągu wiejskiego przedstawione i omówione zostały poszczególne metody i ich założenia.

Słowa kluczowe: EV, prognozowanie, ES, PV, ED

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1. Introduction

Earned Value (EV) or, more broadly, Earned Value Management is a technique used to monitor project implementation progress. This method combines the possibility of verification of the schedule scope and the cost of tasks in the project. The methodology was introduced in the 1960's by the United States Department of Defense. The aim was to obtain the full scope of knowledge on all projects financed by the state budget and effectiveness of the funds spent on these [3]. The method was based on planned value (PV), actual cost (AC) and earned value (EV) which allows for determining the rate of project advancement, detecting any delays or the possibility of exceeding the budget, while specifying the causes. On the basis of the data above, it is possible to determine cost variance (CV), schedule variance (SV), schedule performance index (SPI) and the Cost Performance Index (CPI). In 1998, official ANSI/EIA-748 standards and guidelines were published [1] for the purpose of popularizing the method both in public and private procurement procedures. Since then, many publications dedicated to this methodology have become available. The aspects, in which the methodology is subject to development, have been divided by the author of this article into several groups:

- Method of determination of the quantity of works performed and the accuracy of data influence on the correctness of calculations made. In literature, there are many approaches to this issue which have been described, proposing that values are expressed as percentages, e.g. in the proportion of 50/50, 0/100 analyzed by [6], 10/90, 20/80, 25/75, and the recently proposed method for determining the quantity of works performed using the fuzzy-logic method [8];
- Tools and applications. The calculation-supporting tools that have been proposed include: MS Project, Primavera 6, Developed Software [13] and Pro track [20];
- Final cost forecasting. This issue has been discussed in many publications, including [5], [6], [12, 19];
- Final schedule forecasting. Many calculation methods are proposed and developed in the literature, including the following publications: [2, 4, 8, 10, 11, 15].

This article focuses on the last issue. Research conducted so far [2, 4, 8, 10, 11, 15] indicates that on the basis of current project inspections and emerging trends, it is possible to forecast the project completion date with a high level of accuracy.

After a review of the studies quoted above, calculations were conducted for a completed facility constructed in Lesser Poland (małopolskie).

2. Calculation example

Calculations were conducted using an investment project, completed in the period between December 2011 and January 2013 as an example. The investment scope included the construction of a domestic sewage system with a high pressure pumping station, a power generator building with a water supply line to the pumping station and a power supply, an access road to the pumping station, as well as relocation of an existing water supply pipeline, ditch bridging and finally, laying a rainwater sewage line culvert in the ditch. The agreement between the contractor and the investor was signed on the basis of a quantity survey. The

Table 1

The EVM system parameters for the example being analyzed (source: own work)

Par	Duration													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
PV	83 003	198 146	405 463	503 024	746 927	974 569	1275382	1576195	1828228	2023350	2072130	2129041	2199140	2416637
%	3,43%	8,2 0%	16,78%	20,82%	30,91%	40,3 3%	52,7 8%	65,2 2%	75,6 5%	83,7 3%	85,7 4%	88,1 0%	91,0 0%	100%
EV	83 018	295 350	444 895	663 233	876 811	1070727	1299499	1514871	1680354	1977133	2124807	2277551	2319972	2370103
%	3,4 4%	12,22%	18,41%	27,44%	36,28%	44,3 1%	53,7 7%	62,6 9%	69,5 3%	81,8 1%	87,9 2%	94,2 4%	96,0 0%	98,0 7%
AC	98 787	342 327	504 677	742 999	958 705	122 6926	1404207	1503336	1618816	1749325	1904149	2008181	2127824	2167310
SV	16	97 204	39 432	160 209	129 884	96 158	24 117	–61 325	–147 874	–46 217	52 677	148 510	120 832	–46 534
SV%	0, 0%	49, 1%	9, 7%	31, 8%	17, 4%	9, 9%	1, 9%	–3, 9%	–8, 1%	–2, 3%	2, 5%	7, 0%	5, 5%	–1, 9%
CV	–15 769	–46 977	–59 782	–79 766	–81 893	–156 199	–104 708	11 534	61 538	227 808	220 658	269 370	192 148	202 794
CV%	–19, 0%	–15, 9%	–13, 4%	–12, 0%	–9, 3%	–14, 6%	–8, 1%	0, 8%	3, 7%	11, 5%	10, 4%	11, 8%	8, 3%	8, 6%
CPI	0,84	0,86	0,88	0,89	0,91	0,87	0,93	1,01	1,04	1,13	1,12	1,13	1,09	1,09
SPI	1,00	1,49	1,10	1,32	1,17	1,10	1,02	0,96	0,92	0,98	1,03	1,07	1,05	0,98

planned investment value was about PLN 2 420 000, and the planned duration time was 14 months.

During implementation, financial settlements were carried out and measurement cards were prepared on a monthly basis, which specified in detail, the quantity and progress of all types of works. Calculations using EV was conducted on the basis of data received from the contractor, upon completion of the investment project. The results of EV calculations are presented in table 1.

Assumptions made for calculation purposes:

- PV. The planned progress of works, while planned costs were determined on the basis of the schedule of works and expenditures, agreed upon with the Investor;
- EV. The actual progress of works was determined on the basis of measurement cards for individual cost estimate items;
- AC. The real costs incurred in the settlement periods, taking into account the direct construction costs established on the basis of the invoices and settlement protocols, and indirect costs.

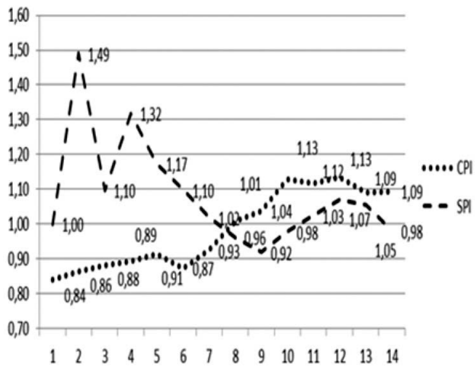

Fig. 1. SPI and CPI value (source: own work)

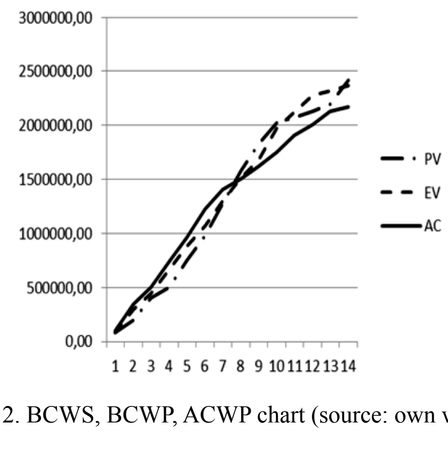

Fig. 2. BCWS, BCWP, ACWP chart (source: own work)

The values of selected indices applied in the EVM method are interpreted as follows:

- CPI, SPI > 1 performance below the cost planned, faster than planned; < 1 above the budget planned, slower than planned; = 1 accordingly with the cost and schedule planned.
- Since the calculation results, obtained so far, serve as a basis for further analysis, the author has summarized these in three short points:
- SPI, CPI. Early months of performance – work was conducted at a much faster pace, while higher costs were incurred. Months 8–10 – a delays were recorded, but the SPI value remained high at > 0,9. During the following months – until the end, the facility was completed at a faster pace than planned and at a lower costs (Fig. 1).
- The time planned for completion of the project took longer than needed. This resulted in performance of works in steps. Sometimes, the Contractor accelerated the works to complete a given stage, or delayed the commencement of another stage of works.
- The facility was constructed by the contractual deadline below the budget planned. The scope turned out to be 2% lower than planned (about PLN 46 000). The total profit from the project amounted to PLN 200 000, which constitutes to more than 9% of the value of all works performed (Fig. 2).

3. Final schedule forecasting

All EV parameters have been expressed in monetary units, including schedule variance (SV) and schedule performance index (SPI). In addition, the calculations and analyses quoted in literature suggest that the values of both indices for the final period of project implementation assume erroneous values [4, 10]. These difficulties have led to emergence and development of the following methods used to forecast the final schedule: the planned value method [2], the earned duration method [8] and the earned schedule method [10]. Each of these methods can be used under the following circumstances:

- The final project schedule will be as planned, regardless of progress of the project in the past;
- The planned schedule for completion of the remaining works is unattainable due to a change in the conditions – a new schedule should be established for these;
- The date of completion of the remaining works is much delayed; due to technical problems, successful completion of the project becomes highly questionable;
- The remaining works will be completed as planned; progress of works in the past will be of no impact upon these;
- Progress of works in the past will impact on future works, which will be adapted to the current conditions;
- Progress of works in the past (both the cost and the time) will exert an impact upon the remaining works (CR = SCI = SPI×CPI).

The author decided to conduct calculations for the last three variants in accordance with the suggestions provided in the study [15], and applied the standardized nomenclature, proposed by the authors of the study. Formulas for individual variants in individual approaches have been presented in Table 2.

Table 2

A breakdown of calculation formulas for determination of the final schedule EAC(t) (source: own work)

Estimate at Completion EAC(t)		
Index	Calculation formula	Approach
Anbari, The planned value method, 2003		
EAC(t)PV1	EAC(t)PV1 = SAC – TV	Duration of remaining work as planned
EAC(t)PV2	EAC(t)PV2 = PD/SPI	Duration of remaining work follows the current SPI trend
EAC(t)PV3	EAC(t)PV3=PD/SCI	Duration of remaining work follows the current SCI trend
	TV =SV/PVRate = (SV*PD) / BAC = (EV–PV)* PD/BAC	
	PVRate = BAC/PD	
CR/SCI	CSI = CPI*SPI	
Jackob and Kane, The earned duration method, 2003		
AD<PD	EAC(t)ED = AD + (PD-ED)/PF	
AD>PD	EAC(t)ED = AD + (AD-ED)/PF	
EAC(t) ED1	EAC(t)ED1 = AD + (PD-ED)/1=PD + AD*(1-SPI)	Duration of remaining work as planned; PF = 1
EAC(t) ED2	EAC(t)ED2 = AD + (PD-ED)/SPI=PD/SPI	Duration of remaining work follows the current SPI trend; PF = SPI
EAC(t) ED3	EAC(t)ED3 = AD + (PD-ED)/SCI = PD/SCI + AD*(1-1/CPI)	Duration of remaining work follows the current SCI trend; PF = SCI
	ED = AD*SPI	
Lipke, The earned schedule method, 2004		
	EAC(t)ES = AD + (PD-ES)/PF	
EAC(t) ES1	EAC(t)ES1 = AD + (PD-ES)/1 = AD + (PD-ES)	Duration of remaining work as planned; PF = 1
EAC(t) ES2	EAC(t)ES2 = AD + (PD-ES)/SPI (t)	Duration of remaining work follows the current SPI trend; PF = SPI(t)
EAC(t) ES3	EAC(t)ES3 = AD+(PD-ES)/(CPI*SPI(t)) = AD + (PD-ES)/SCI(t)	Duration of remaining work follows the current SCI trend; PF = SCI(t)
	ES = N + (EV-PVn)/(PVn + 1 – PVn)	
	SPI(t) = ES/AT	
	SCI(t) = CPI*SPI(t)	

Table 3

Breakdown of EAC (t) value on the basis of the proposed calculation methods (source: own work)

PD	1	2	3	4	5	6	7	8	9	10	11	12	13	14
PV1	14,0	13,4	13,8	13,1	13,3	13,4	13,9	14,4	14,9	14,3	13,7	13,1	13,3	14,3
PV2	14,0	9,4	12,8	10,6	11,9	12,7	13,7	14,6	15,2	14,3	13,7	13,1	13,3	14,3
PV3	16,7	10,9	14,5	11,9	13,0	14,6	14,9	14,5	14,7	12,7	12,2	11,5	12,2	13,1
ED1	14,0	13,0	13,7	12,7	13,1	13,4	13,9	14,3	14,7	14,2	13,7	13,2	13,3	14,3
ED2	14,0	9,4	12,8	10,6	11,9	12,7	13,7	14,6	15,2	14,3	13,7	13,1	13,3	14,3
ED3	16,5	10,6	14,1	11,4	12,6	13,7	14,3	14,5	15,0	13,8	13,4	13,0	13,2	14,3
ES1	14,0	13,5	13,6	13,3	13,4	13,7	13,9	14,2	14,8	14,9	13,1	11,9	14,2	15,2
ES2	14,0	11,3	12,3	12,0	12,6	13,3	13,8	14,4	15,3	15,5	12,9	11,9	14,2	15,3
ES3	16,5	11,0	14,0	11,9	12,9	14,0	14,3	14,4	15,0	14,5	12,8	11,9	14,0	15,1

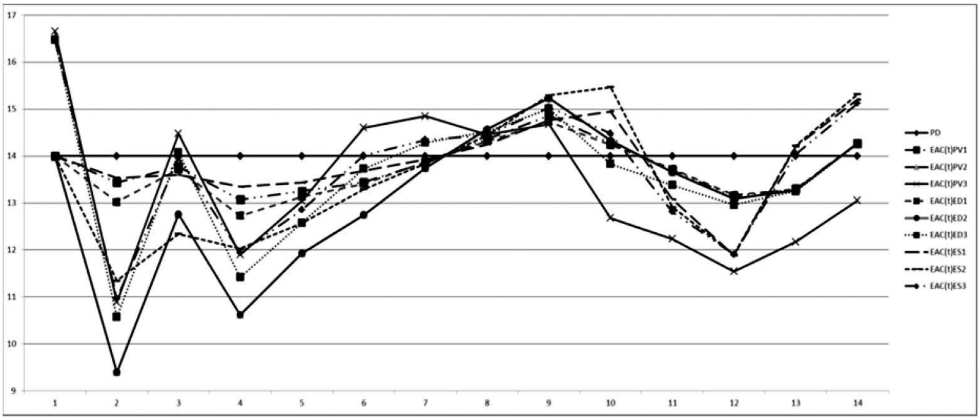

Fig. 3. Chart of results for EAC (t) developed on the basis of Table 3 (source: own work)

The calculation results [see Table 3] indicate a relatively significant discrepancy in the value of EAC(t) obtained on the basis of individual formulas:

- The most significant discrepancy can be observed after 1/3 of the Project duration; forecast time ranges from 9 to 17 months.
- After 2/3 of the project duration, results stabilized at a level similar to the project duration time (actual and planned).
- EAC(t) ED2 and EAC(t) PV2 results assume the same values.
- The least reliable results were observed for formulas EAC(t) ES2 and EAC(t) ES3.
- Results closest to actual values were observed in the case of EAC(t) PV1, EAC(t) ED1 and EAC(t) ES1.

- Fluctuations of the EAC(t) curves can be observed in those locations, in which substantial deviation of the actual progress of works occurred in relation to the baseline plan.

4. Conclusions

On the basis of the calculations performed, the author observed the following regularities:

- The analysis indicates positive results for the EV method, as a tool for project controlling in terms of the costs incurred and progress of works;
- The results of the final schedule forecasts are not reliable during the early phase of the project (1/3), they stabilize in the middle, and only in the final phase of the project, become highly probable;
- In the example presented, the results were obtained for all methods using the approach „performance as planned" – which is not consistent with information provided in the literature [11, 15], in which the Earned Schedule (ES) obtains the most reliable results in most of the cases analyzed;
- Disturbing the planned progress of works due to temporary acceleration and delaying of works exert significant impact on correctness of the forecast results.

The calculations performed do not conclusively prove the correctness of the formulas applied. In the case analyzed, the approach „project performer as planned" attained the results closest to the actual values in each of the proposed methods [2, 8, 10]. The ES results, unlike in the examples quoted in literature [11, 15], differed most from the actual values. Such results may be obtained in a situation, in which it is assumed in advance that the planned performance period would not be changed, and works would be delayed or accelerated only temporarily. Such performance of works in steps results in forecast errors; assumptions made in order to meet the deadline established in the forecast, in accordance with the plan. The analysis conducted has confirmed this assumption.

The issue of forecasting should be developed further in order to obtain more accurate information, confirmed by analysis using a greater number of exemplary projects, carried out under varied conditions, taking the mode and accuracy of the data collected into account.

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THE INFLUENCE OF STOPPAGES ON PRODUCTIVITY DURING CONSTRUCTION OF WATER SUPPLY AND SEWAGE SYSTEMS

WPŁYW PRZERW NA PRODUKTYWNOŚĆ PRACY PRZY BUDOWIE SIECI WODOCIĄGOWYCH I KANALIZACYJNYCH

A b s t r a c t

This paper analyses the causes and consequences of stoppages due to cuts in the water supply and sewage systems installations. The bases for the article are direct observations conducted on 8 building projects.

Keywords: productivity, stoppages, water supply and sewage systems constructions

S t r e s z c z e n i e

W artykule przedstawiona została analiza przyczyn i skutków przerw w pracy przy budowie sieci wodociągowych i kanalizacyjnych. Podstawę artykułu stanowią bezpośrednie obserwacje przeprowadzone na 8 obiektach.

Słowa kluczowe: produktywność, przerwy w pracy, budowa sieci wodociągowych i kanalizacyjnych

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1. Introduction

One of the basic factors linked to the operational efficiency of an enterprise is productivity. Productivity should therefore be used as a primary factor in the assessment of building firm activities [8]. For building companies operating in the current difficult economic environment, any productivity increase brings particular benefits, constituting towards improvements, competitiveness and increased financial gain. Productivity is the ratio of goods and services to the resources used in labor, materials, energy and capital [4]. Productivity increases can be achieved by means of non-investment activities e.g. by improving the construction process organization and making better use of production resources, tools and manpower.

Actions taken to increase productivity should consist of, among other things, shortening the time planned for the task [6], which is largely based on reducing the frequency and duration of stoppages. Stoppages can be caused by external, as well as internal factors. External causes are essentially beyond company control, however, it is possible to eliminate or limit adverse stoppages, to shape growth and productivity in order to enhance the economic efficiency of construction processes. This however, can only take place after a diagnosis of the causes of any internal factors.

The aim of this paper is to identify the causes of stoppages during water supply and sewage systems installations, as well as to identify the technological stages of construction during which such stoppages occur. The basis for the article is direct observation carried out on construction sites. Information on the subject is useful for improving the construction process in terms of increasing its productivity. Frequently reported delays in construction time, including those relating to water supply and sewerage works are symptomatic of the need for such research. Failure to meet specified deadlines and calculating contractual penalties, weaken the contractors position in the construction market.

2. Subject of research study

Direct observation were carried out on eight building sites where water supply and sewage system installations were taking place. These were executed between 2010–2013, in the provinces of Lower Silesia and Opole. Each of these investments were carried out by different contractors. The scope of works conducted during the period of observation included the following processes:

- earthwork – excavations, pipe bedding, backfill and compaction;
- installation of pipeline and fittings;
- control work – survey work and pipeline testing;
- finishing work – land reconstruction and reclamation, removal of excess soil.

The period of each project execution is shown in Fig. 2. The top line in the Gantt's chart indicates the dates stated in the contract, while the bottom, those actually met. From the schedule presented on Fig. 1, it appears that the building works on all objects were conducted in the same seasons of the year. An analysis of documentation demonstrated that only one of them (B5) was completed on time.

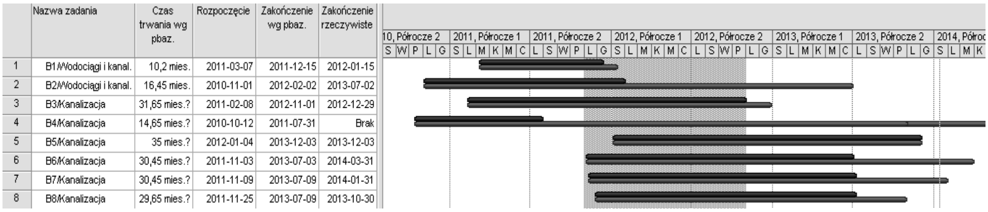

Fig. 1. The schedule of work on objects of research study

3. Method of research study

In order to identify and classify the stoppages, the following research methods were implemented:

- documentation review,
- direct observation on the work station on the building site,
- interviews with the persons responsible for the timely execution of processes.

The documentation review included an analyses of the following documents: design documentation, specifications, Records of Necessity and Negotiations, the building diary, Contractor's reports and programmes, as well as correspondence within the contract.

The research was carried out from November 2011 to October 2012. Direct observations were of a shutter nature and concerned particular work stations. The state of work or stoppages on workstations was recorded randomly by the observer. In case of stoppages, the reasons were determined. On each construction the same number of observations was carried out. The results of measurements were noted in a specially prepared questionnaire. The choice of such a research method was dictated on the basis of continuity and repeatability of the work.

In most cases, at the moment of record, the work was ongoing on stations. Stoppages were found 52 times (for a total number of observation: 192), which represents 27% of all observations. Relating the result to the classification used in construction [8] it can be stated that the activity of the production teams on the constructions analysed was at a "normal level". Such a level is defined as corresponding to three quarters of optimal performance. However, the optimal effect occurs when skilled workers do not have to work after hours, provided that they follow the established work method. 98% of the contractors in the building industry reach normal levels of activity [8]. Based on the research results, all of the contractors under observation could be listed in this category.

Actions for increasing productivity require improvements in work efficiency. It is therefore important to strive to eliminate, or limit, stoppages. Based on data from the observations, three sets of elements were associated with the occurrence of stoppages were distinguished. These are:

- factors causing the stoppage of production teams,
- type of work
- building project under analysis.

A matrix diagram was compiled in order to determine the relationship between the elements of these sets, as shown in Fig. 3. In this diagram, the measure of the relationship between each element is the number of stoppages observed during the research. For example, during

3		1				1		1	Land reconstruction and reclamation				1	2		
2						1	1		Backfill			2				
3		1		2					Installation of fittings			1		2		
16		1	1	4		4	6		Installation of pipeline	1		10	5			
2				1			1		Pipe bedding					2		
26			5	10	8	1	2		Excavations	8	2	1	1	8	5	1
Total	B8	B7	B6	B5	B4	B3	B2	B1		Formal and legal problems	Faults in Project documentation	Adverse weather conditions	Faulty work organization	Violation of work rules	Regular breaks	Collisions
9			1		8											
2			2													
14		1	1			5	7									
7		1		4			1	1								
14			2	7	1	2	2									
5				5												
1				1												

Fig. 2. The occurrence of stoppages on the objects of research study

a manhole installation, three stoppages were reported (on objects B7 and B5), wherein one of them was caused by bad weather, and the other two by violation of work rules. However, the total number of stoppages due to bad weather conditions on all sites was 14 (1 + 1 + 5 + 7).

The placement of the stoppages in the rows and columns of the diagram indicates the random nature of their occurrence. This makes it difficult to develop a strategy that allows a reduction in their number. For this reason, each set was analysed separately. The basis for the analysis is the relationship between each element of the set and the number of stoppages observed. Result of the analysis are presented in Fig. 3.

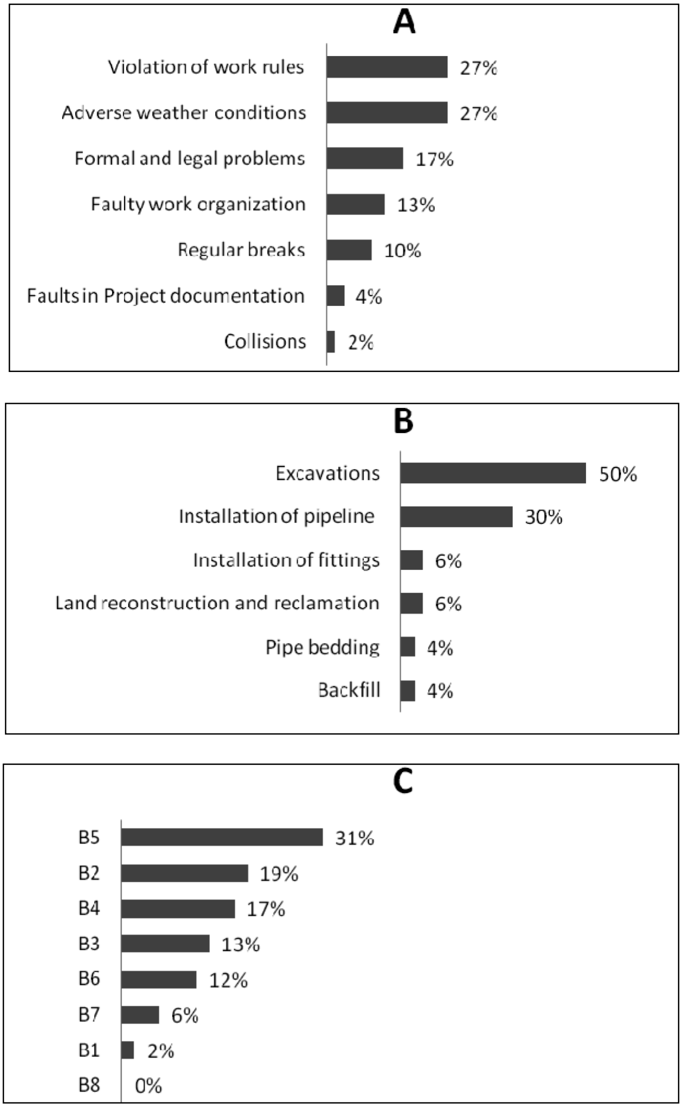

Fig. 3. Structure of the occurrence of stoppages observed on objects of the research study

The classification of stoppages shown in Fig. 3A, 3B, 3C allows us to conclude that the responsibility for stoppages of work on water supply and sewage systems construction is held by both managers and workers. Managers are responsible for: choosing suitable dates for particular works during periods of adverse weather conditions (winter), the occurrence of formal and legal problems during the work (lack of documents required to carry out the work) and faulty work organization. These factors resulted in 50% of stoppages. Particular attention should be paid to the fact that the weather risk is not taken into consideration in the signed contracts, although this problem is already well recognized in the construction industry [1, 3, 7, 10]. The schedule presented in Fig. 2 is evidence of this. All of the projects under observation started in October – November, so that their execution always fell in winter, and therefore burdened with the greatest probability of adverse weather conditions.

From Fig. 3B, it appears that the causes of stoppages were violations of work rules by employees, to the same degree as adverse weather conditions. Observations have demonstrated that they arise most often from a lack of direct supervision. Violation of work rules mainly consisted of delays, unplanned breaks and unexplained abandoning of the work position.

In the case of works related to water supply and sewerage systems, two critical technological processes should be considered: excavations and pipeline installation. These works should not be executed during winter, as they are particularly sensitive to temperatures below zero (ground freezing, low resistance of pipes and fittings, lack of possibility for pipe testing).

The existence of significant production reserves on construction of water supply and sewerage systems is indicated in Fig. 3C. Construction no. B5 is an example of this. Despite incurring the largest number of stoppages during execution, this was the only investment to be completed on time. In contrast, there were no stoppages on construction B8, but the duration of this project was prolonged. ’The Organization and Management Encyclopaedia’ defines “reserve” as “... the unused part of production potential” [2]. The under load or slack of work stations is regarded as a production reserve. This concerns the next problem in production process organization determines the appropriate level of reserves related to the under loading of work stations. Some reserves should be kept in case of disturbances in the production system. On the other hand, it should be considered that too low a load results in losses. Determining the optimal level of these reserves is a difficult issue and should be associated with the analysis of time and cost risk of an executed object [5, 9] as well as its individual circumstances.

4. Conclusions

Construction project management is effective when it is based on facts, and not on speculative or unverified assumptions. Therefore, work stoppages, their frequency and their causes were analysed in the article. By eliminating these stoppages, a company can improve its activity index, which is labor productivity. As a result, the economic efficiency achieved by the firm can be raised.

The research findings indicate that actions for productivity should be taken by every employee, from contractors through direct supervision of the construction, to the management of the company involved in the planning of the work. This is indicated by the most frequently noted causes of stoppages: violation of work rules, faulty organization, execution of work during periods of the adverse weather conditions.

The research conducted draws attention to the need to resolve the problem of the amount of production reserves during the installation of water supply and sewage systems. One of the components necessary for the proper determination of their level is to identify interferences in the production process and then take appropriate actions to eliminate them, or reduce them to the minimum level. The higher the number of building objects covered by observation and analysis related to the causes of stoppages, the more reliable the results will be.

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