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

2-B/2014

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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.

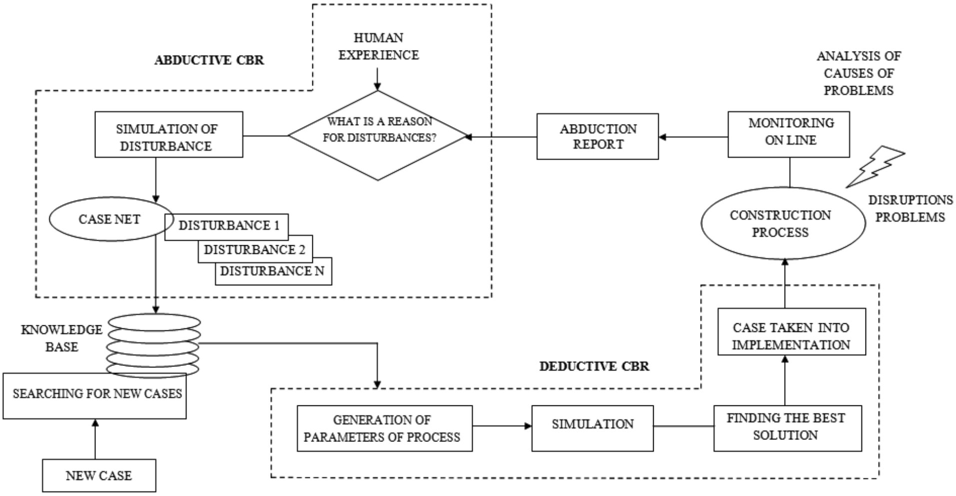

Fig. 1. An idea of abductive and deductive CBR approach by simulation

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.

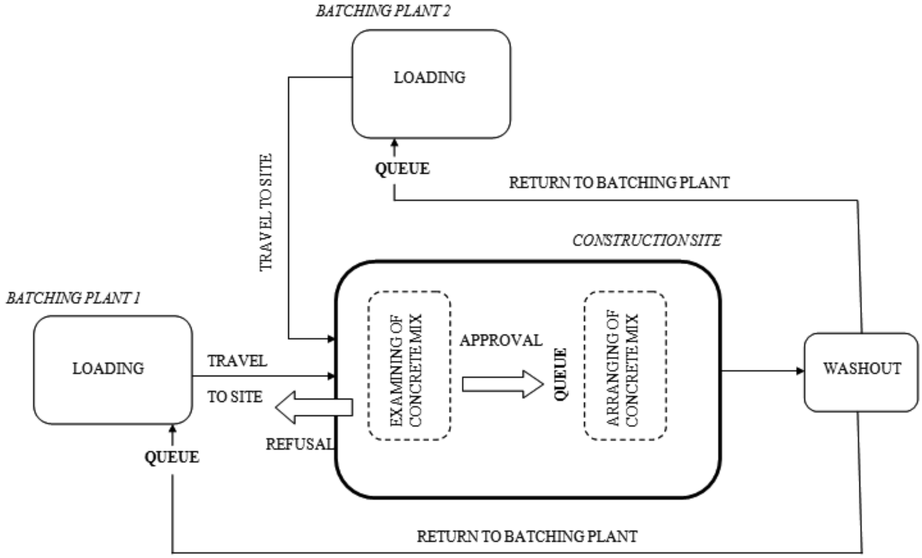

Fig. 2. Delivery of ready-mix concrete

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.

The authors would like to thank the Institute of Structural Engineering of the Poznan University of Technology for the support from its statutory activities fund.

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