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A CONCEPT OF AN INTEGRATED CONSTRUCTION PLANNING SYSTEM INVOLVING LOCATION-BASED SCHEDULING TECHNIQUE

KONCEPCJA ZINTEGROWANEGO SYSTEMU PLANOWANIA PRZEDSIĘWZIĘĆ WYKORZYSTUJĄCA TECHNIKĘ LBS

A b s t r a c t

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

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

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.

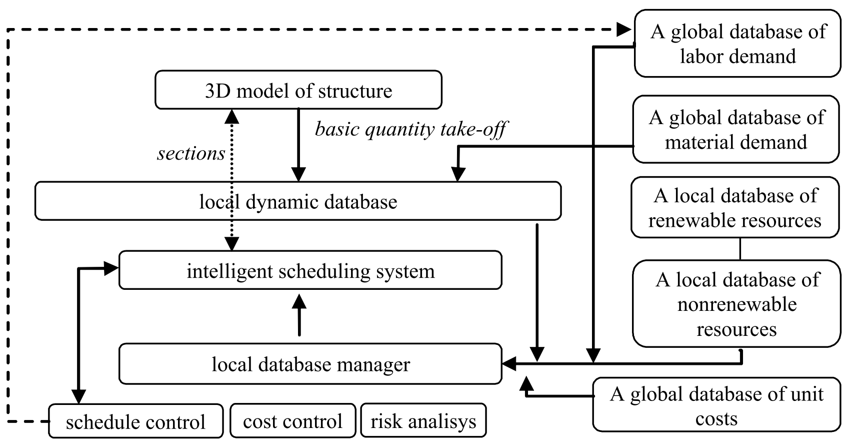

Fig. 1. The idea scheme of an effective multilevel planning system, author's elaboration

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 ($k = 1, 2, \ldots, K_i$) 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 $i = 1, 2, \ldots I$). 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.

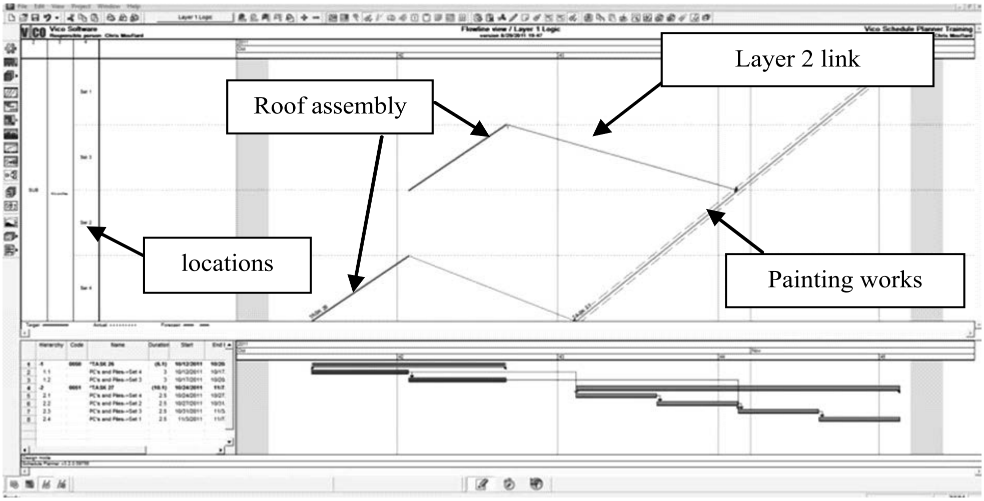

Fig. 2. An example of layer 2 logic link, *Vico software* window view

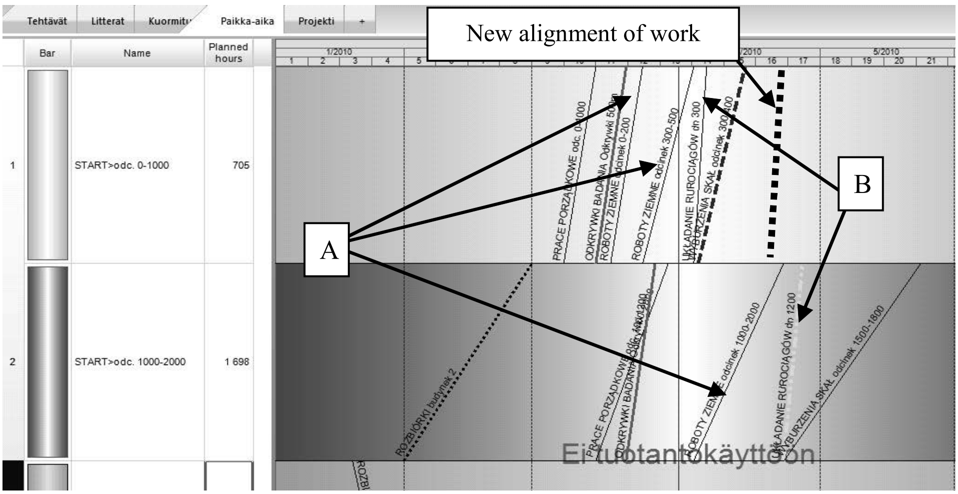

Fig. 3. An example of layer 3 logic links, *PlanMan Project 2012 demo* window view

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!*

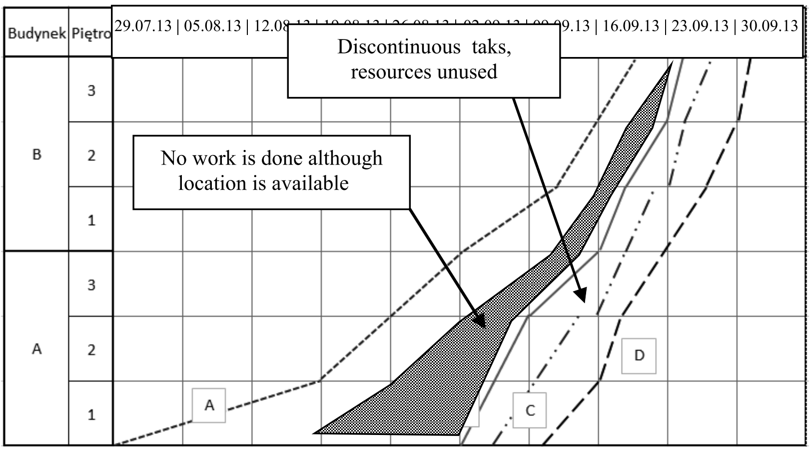

Fig. 4. An example flow-line chart before adjustment

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.

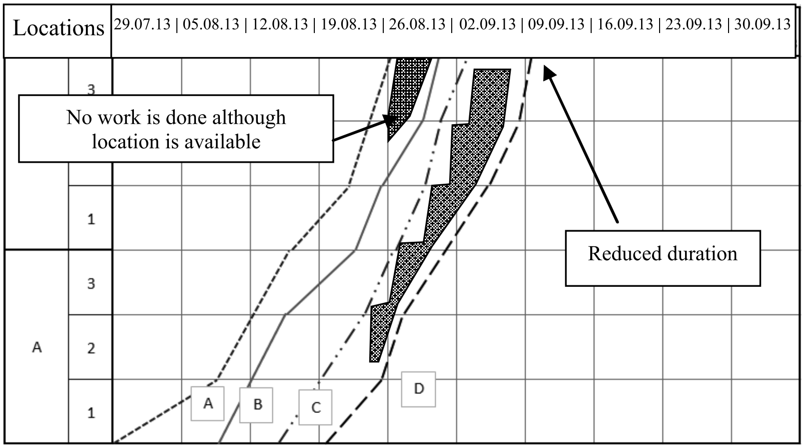

Fig. 5. An example flow-line chart after adjustment

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.

References

[1] Marcinkowski R., Krawczyńska A., *Koncepcja metody analizy efektywności wykorzystania deskowań systemowych w budowie obiektu żelbetowego*, Zeszyty Naukowe Politechniki Rzeszowskiej, Vol. 58, No. 3/2011/III, 2011, 257-264.

[2] Krawczyńska A., *Wybór systemu i planowanie organizacji wykorzystania deskowań systemowych w wykonawstwie konstrukcji betonowych,* Problemy naukowo-badawcze budownictwa, Płockie Forum Budowlane, Płock 2010, 203-214.

[3] Andersson N., Christensen K., *Practical implications of location-based scheduling*, Proc. CME25: Construction Management and Economics: past, present and future, University of Reading, Taylor and Francis Group, London 2007.

[4] Kenley R., Seppänen O., *Location based management for Construction – Planning, Scheduling and Control*, Spon Press, London–New York, 2010.

[5] Chen S-M. et al, *A framework for an automated and integrated project scheduling and management system*, Automation in Construction, Vol. 35, 2013, 89-110.

[6] Song S. et al., *Development of a BIM-based structural framework optimization and simulation system for building construction*, Computers in Industry, Vol. 63, 2012, 895-912.

[7] Monteiro A., Martins J., *A survey on modeling guidelines for quantity takeoff-oriented BIM-based design*, Automation in Construction, Vol. 35, 2013, 238-253.

[8] Jongelin R., Ojoffson T., *A method for planning of work-flow by combined use of location-based scheduling and 4D CAD*, Automation in Construction, Vol. 16, 2007, 189-198.