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VISUALIZING SIMULATED MONOLITHIC CONSTRUCTION PROCESSES

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Abstract. This paper concerns visualizing simulated construction processes by using two modules, which are part of the expert system. Modelling and analyzing construction processes by using simulation and visualizing results technique allows participants to provide an in-depth insight into this complex undertaking. The system discussed has a hierarchical and modular structure and is designed for monolithic constructions. Major elements of this system are objects such as: concrete mixers, buckets, slip forms, cranes and a building team. The paper describes the work of two modules that enable combining production systems of sets of means, simulation, and visualisation results. Simulation is a valuable tool in analyzing construction process because it allows construction designers to carry out experiments that make evaluation of different variants possible. Visualizations presented offer an insightful approach to understand complexities of the construction process. The dynamic nature of the construction process has been taken into account and is handled by the system.

Keywords: construction operations, monolithic construction processes, decision support and expert systems, modelling, simulation and visualisation.

1. Introduction

This paper deals with decision support (DSS) and expert systems (ES) as well as modelling and simulation (M&S) domain. Construction investment process is a long-term and complex activity during which numerous problems occur. Expert systems, simulation and visualization tools as well as multi-criteria optimization methods in many aspects and stages of the investment process have advanced considerably in recent times.

1.1. Literature review

Issues of decision support and expert systems in structural engineering domain were discussed in works of Adeli (1988); Brandon *et al.* (1988); Durkin (1994); Anderson (1996); Poon *et al.* (2000, 2003; Poon 2004); Mitkus and Trinkuniene (2006); Kaklauskas *et al.* (2005, 2007a); Zavadskas *et al.* (2006); Golabchi (2008). Expert systems development, classification, methodologies and applications from 1995 to 2004 have been discussed by Liao (2005).

Recent literature looks on modelling as a design activity and models as complimentary and alternative media, which are often used in research on construction processes (Ayres 2007). The modelling supports a wide range of construction applications and, among other things, design, construction planning, site layout planning, estimating, valuating and maintenance. The notion of modelling has been widely researched (Dawood 1994; Yang *et al.* 1996; Marlewski and Hajdasz 2000; Aouad *et al.* 2006; Ayers 2007). Researchers have broadly addressed the concept of modeling and employed modelling strategies in various domains of construction. For instance, Yang *et al.* (1996) developed expert systems in construction management; Poon *et al.* (2000, 2003); Poon (2004) introduced a new approach for modelling the construction process based on the use of an expert system; Zhang *et al.* (2005) focused on the consideration of break in modelling of construction processes; Doloi and Jaafari (2002a, b) designed a dynamic simulation model for the strategic decision-making.

Problems in modelling, simulation and optimal managing of building processes are under investigation in theoretical and practical aspects (Kamat and Martinez 2001, 2005; Doloi and Jaafari 2002a, b; Mohamed and AbouRizk 2005; Changwan *et al.* 2006). One of the greatest difficulties in developing simulation models is the ability to realistically present the obtained results. Advanced simulation and visualization relating to the production processes have been discussed among others by Karhu (2003), Sampaio *et al.* (2005), Kamat and Martinez (2005, 2008). Multicriteria decision-making methods have been applied in various aspects of the investment process (Kaklauskas *et al.* 2007a, b; Mitkus and Trinkuniene 2007; Banaitienė *et al.* 2008). This area has been explored by Zavadskas *et al.* (2003), who discussed problems of selection of rational construction variants, also, Zavadskas *et al.* (2008) presented a new method of multiple criteria complex proportional assessment with values determined in intervals – COPRAS-G; Grierson and Khajehpour (2002) introduced a computer-based method for the multicriteria conceptual design of

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high-rise office buildings; Hajdasz and Marlewski (1999) developed a multicriteria analysis of the construction process. The author of this paper has continued research on monolithic constructions and linked the study of expert systems and modelling with simulation and visualization of the results obtained. The use of virtual reality techniques and new perspectives to teaching subjects related to the field of civil construction are widely discussed in works of Marlewski and Hajdasz (2000) and Sampaio *et al.* (2005). The extensive critical review of the construction process models has been discussed by Poon *et al.* (2003).

1.2. The aim of research

The system presented belongs to a group of tools which provide a new quality in designing construction process by introducing simulation of modelled processes. The author has employed in this article a slightly different approach to discuss issues concerning visualization techniques in construction. In this approach a strong emphasis has been put on the visualization and descriptive analysis of phenomena taking place in construction processes rather than on their realistic description. Therefore, the aim of this research is not to create a realistic 3D animation, but to provide a thorough analysis in which visualizations are helpful in understanding the whole process.

This paper on the one hand reveals the work of the expert system designed and, on the other, it presents analytical capabilities of the selected modules. The working of the two modules concerns: process simulation (SiCE) and combination of co-operating machines and groups of workers (CoCE) and visualization of the results obtained in the process of working of these modules. The modules are: Simulation of Co-operating Elements (SiCE) and Combination of Co-operating Elements (CoCE). The visualization qualities of the SiCE and CoCE modules will be discussed in particular. In order to highlight these qualities a picture of the working of the acceptance of crane module has been included in the discussion.

The expert system presented is concerned with technology designing and monolithic processes organization and is controlled by decision-maker's preferences revealed during a dialogue session. This paper discusses a selected issue of a complex cyclic process which is the efficiency change of the production set, when the construction rises. When the height of the object changes, it affects the conditions of the realization of the project, which may require modifications of decision maker's preliminary assumptions, if the initial result is to be achieved. This process is of a dynamic nature which is identified and handled by specific modules.

1.3. Expert system and modules

The expert system designed for this research consists of data base, knowledge base, inference mechanism and includes a number of units (modules), such as the procedure for accepting a crane, a module analyzing the work of building gangs, unit arranging a set of objects, scheduling module and a unit, providing the multi-criterion analysis. In this system, as in most expert systems for constructional tasks, the knowledge base consists of a set of facts or object definitions and a set of rules. These rules contain knowledge about correct or ideal solutions as well as knowledge on how to control the construction process. Due to the specific character of the domain, 2 kinds of rules have been distinguished: micro rules, which describe the technological and organizational processes, and macro rules, which control the design process. Modules (SiCE) and (CoCE) exemplify micro rules activities.

The considered expert system architecture is presented in Fig. 1. The following scheme presents a relationship hierarchy of the system elements. Fig. 1 also contains modules not discussed in this paper.

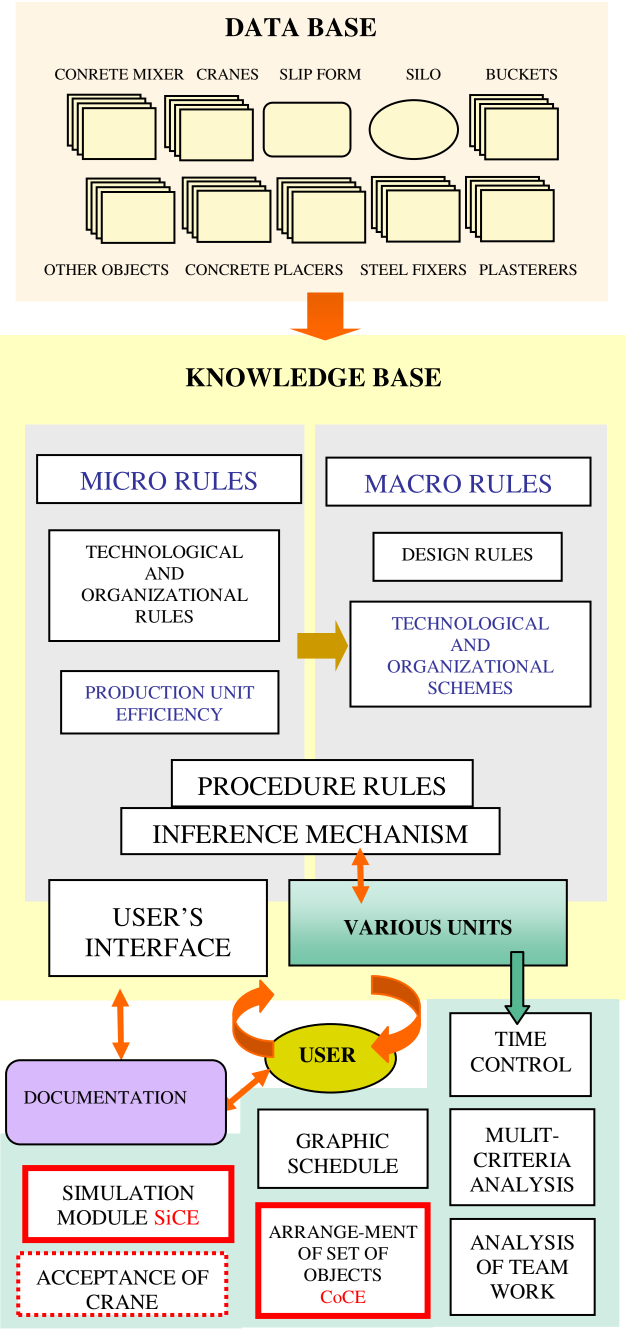


Fig. 1. Expert system architecture

The solutions suggested are universal and applicable to monolithic constructions. Problems presented in the article are discussed on the basis of the example of silos constructed using slip forms. The modules described can work on a stand-alone basis, independently of an expert system. It should be emphasised that the article focuses on presentation of behaviour of processes modelled and on revealing any relations between elements, and not on an analysis of particular data.

The prototype of this expert system and working of selected modules have been further developed by Hajdasz and Marlewski (1998, 1999) and Marlewski, Hajdasz (2000). This system is constantly under investigation as a generalization of the system for the monolithic construction, and is yet to be designed (initially the prototype has been developed for the purpose of the silos construction which has been thoroughly researched by Hajdasz (1998)).

2. A conceptual model of construction process

The complexity and flexibility of the construction process leads to many difficulties in modelling production systems. One of the most important and difficult tasks in creating expert systems are acquisition and representation of the natural knowledge and modelling construction processes.

The article is concerned with cyclic monolithic processes by an example of silos building. Before a model of construction process was made, sub-processes had been created. Then detailed observations, measurements, and analysis of particular sub-processes were carried out. Many sub-models were designed and then they were synthesized to a model of the complex construction process. An expert system was created for this complex process. To illustrate different modelling stages 2 schemes are shown. The first one (Fig. 2) reveals cyclical complex construction process; the second (Fig. 3) shows a submodel as a sequence of repeated activities.

The cyclic character of this process is fleshed out in Fig. 2.

Major elements of this production system are objects, such as concrete mixers, buckets, slip form, cranes and building team. The construction process involves a complex interaction between equipment, crews and materials. A strict technological regime demands all these cooperating elements to be well harmonized. The model is of a universal character for monolithic constructions. After values are added, the model has an individual character.

The designer's problem concerns arranging such resources that make possible the erection of silo walls at determined rate. This requires taking into account the following factors: the concrete casting time, external conditions and the dynamic character of the erection process (the object grows as time goes by). The aim can be achieved by the use of machines, various in type and number, and combining different working gangs. Submodels with their boundaries and interactions are taken into consideration, which allows presenting essential details.

The examples presented below concern a part of the complex process marked with a double line in Fig. 2. All components marked comprise a series of sequentially repeated operations, which have been presented on a network diagram of the model discussed (Fig. 3). Submodel presents sequential and repetitious activities. The operation cycle is repeated. However, according to the specifics of the construction process, these repeating cycles are realized at a different pace, since activities are taking place in different points (in this case at different height).

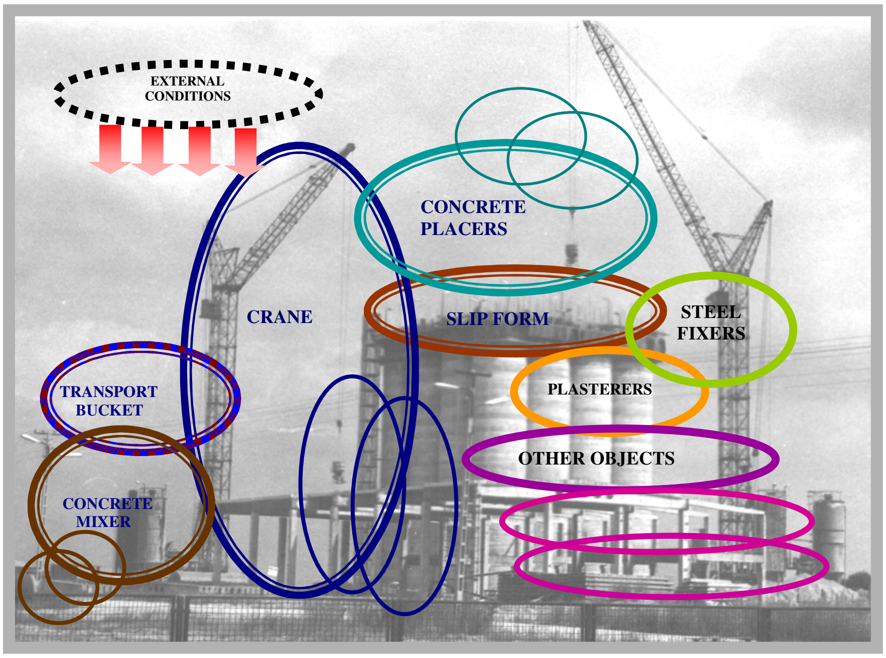


Fig. 2. A conceptual model of complexity cyclical process

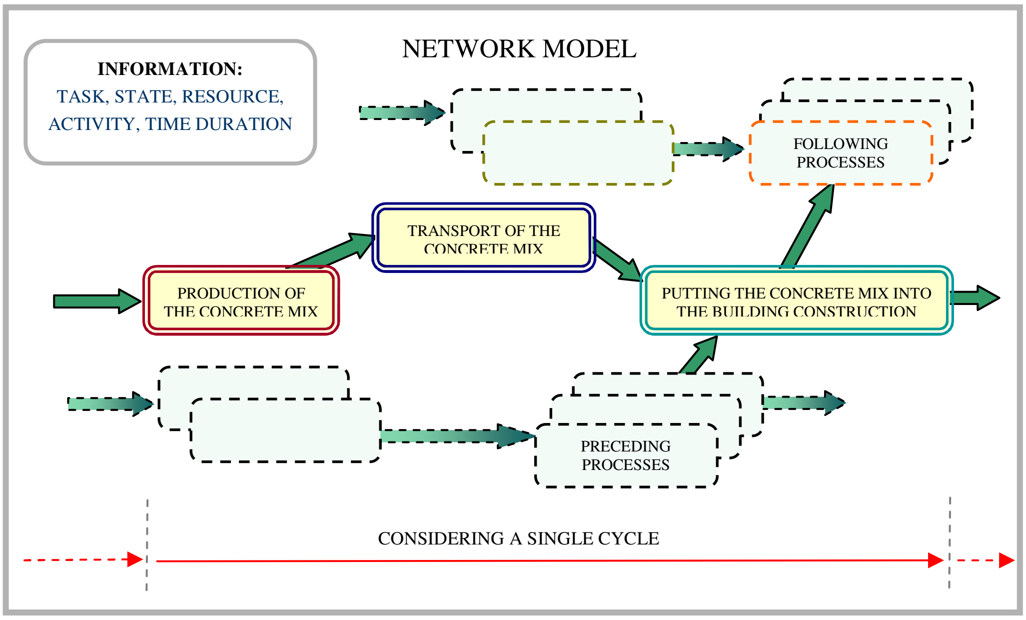


Fig. 3. Submodel presenting chronological sequence of construction operations is shown on the network diagram

Therefore, each current activity is similar, but not the same. It described the behaviour of the processing elements (crews, equipments) and activities (proceeding, temporary, following).

This paper discusses cases, in which harmonisation of all elements of a system is the key criterion (economic aspects are not taken into consideration). In the first case, a simulation of work of a system comprising one crane, appropriate number of concrete mixers, concrete buckets, and a group of concreters has been presented. Analytical and visualization capabilities of SiCE module have been presented in detail. The other example analyses a CoCE module capable of combining sets of a different number of cranes and an appropriate amount of concrete mixers, concrete buckets and concreters in such a way that an uninterrupted work of all components can be ensured. In both cases, a dynamic character of the process has been taken into account.

3. Simulation and process visualization

Simulation is a valuable tool that is well situated to the analysis of construction process because it allows construction designers and analyst to conduct experiments, which enable evaluation of different variants during planning the construction process phases.

The SiCE module is used to visualize several actual construction processes which are tested according to decision-maker's preferences presented during a dialogue session. Many variations of sets of production means for process realization can be generated. Fig. 4 presents a monitor screen illustrating work of SiCe module for the submodel showed in Fig. 3.

The following specification is assumed in this submodel:

- production: a concrete mixer (there is a previously generated base of types of available concrete mixers, marked as CM),
- transport: a crane and a bucket (there is a previously generated base of types of cranes and buckets, which may work on a building site, marked as TB),
- putting into: concrete placers (4 types of operations are distinguished: the receipt of the concrete mixture from a bucket, the spreading and levelling, the vibrating, marked as CP).

Visualization of planned construction operation allows the user to easily and clearly comprehend the dynamic and interrelated behavior of the modelled process after each simulation run.

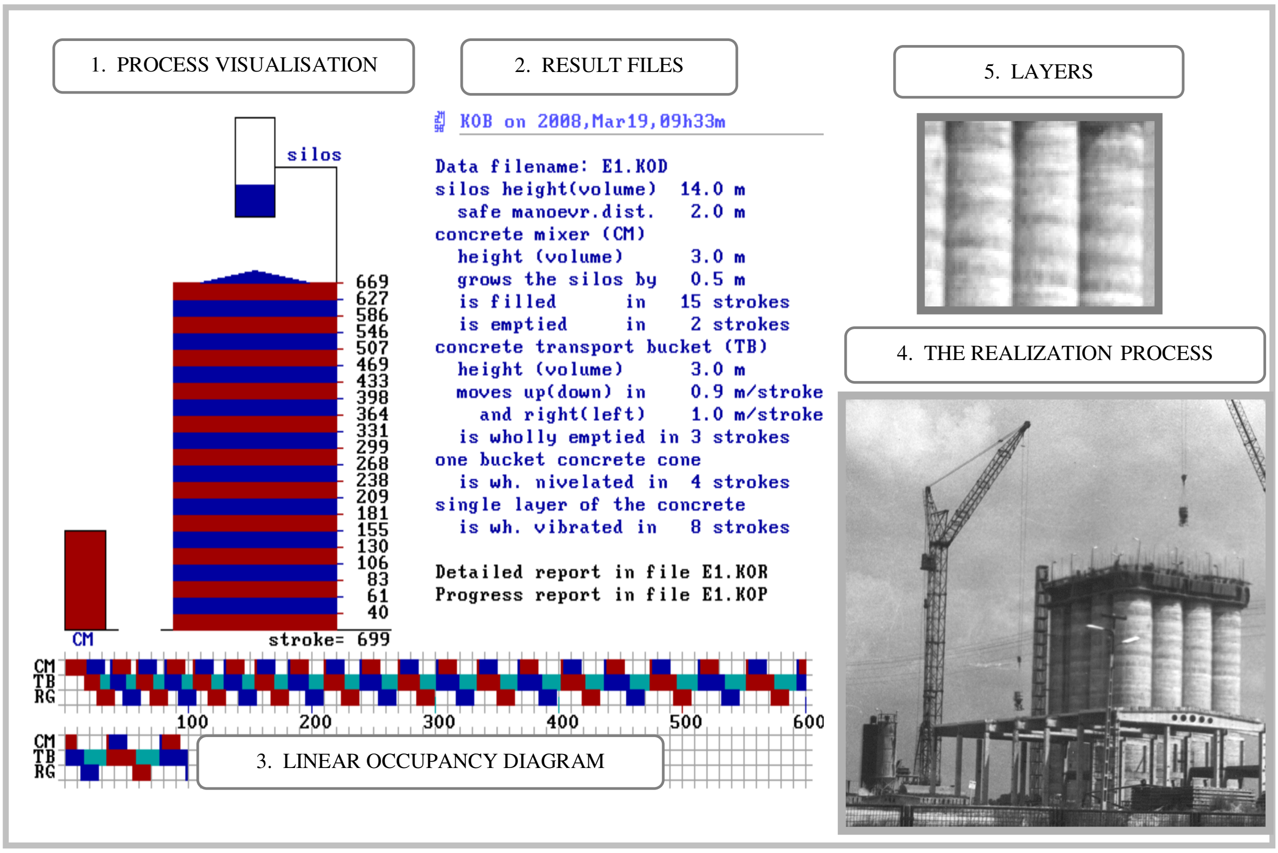
The SiCE module allows for dynamic visualisation of a process that is displayed in a constant mode or interrupted mode, where all following actions start after pressing a button.

A simulation of co-operation of main elements (a concrete mixer, crane transporting bucket and concrete placers) has been presented. A screen displays 3 types of information:

- A dynamic visualisation of progress in construction building and cooperation among elements of a system (left-hand side of a screen, Fig. 4.1).
- A report of production means usage (right-hand side of a screen, Fig. 4.2).
- A linear diagram describing changes in work cycles of system elements (bottom side, Fig. 4.3).

Fig. 4.4 and 4.5 display pictures taken during the process. The comparison of the 2 pictures (Figs 4.1 and 4.4) reveals that thanks to visualization the process description and its analysis is much more comprehensive than we could observe by employing traditional media.

The operation of the SiCE module has to be preceded by a proper selection of cranes, which are to carry out the task. The procedures of selecting the crane have been discussed for the prototype of the system by Hajdasz and Marlewski (1998), Marlewski and Hajdasz (2000), which concerned a non-standard use of a CAS (computer



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KOB on 2008,Mar19,09h33m

Data filename: E1.KOD
silos height(volume)  14.0 m
  safe manoevr.dist.   2.0 m
concrete mixer (CM)
  height (volume)      3.0 m
  grows the silos by   0.5 m
  is filled      in   15 strokes
  is emptied     in    2 strokes
concrete transport bucket (TB)
  height (volume)      3.0 m
  moves up(down) in    0.9 m/stroke
    and right(left)    1.0 m/stroke
  is wholly emptied in 3 strokes
one bucket concrete cone
  is wh. nivelated in  4 strokes
single layer of the concrete
  is wh. vibrated in   8 strokes

Detailed report in file E1.KOR
Progress report in file E1.KOP
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Fig. 4. Full screen produced by the program SiCE (simulation captured at stroke number 669) and pictures concern an example of the realization process. When a monolithic structure is erected, a strict regime must be followed concerning the thickness of concrete layers and the layer solidation time

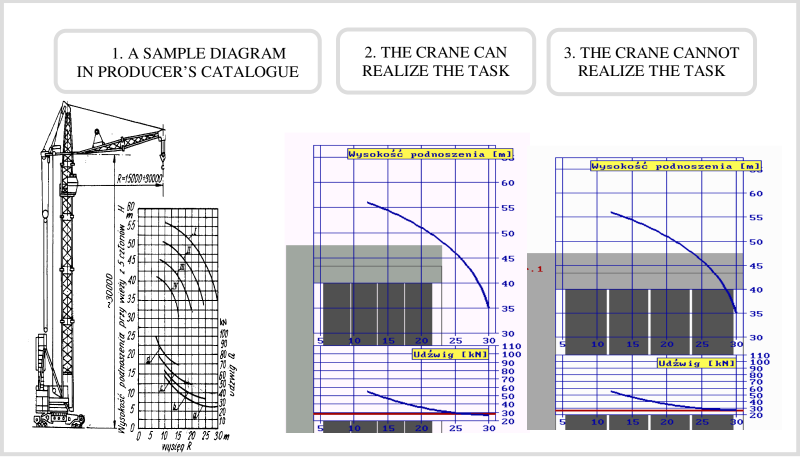


Fig. 5. The comparison with the traditional designing form (Fig. 5.1) is user friendly visualization of the crane operability and the silhouette of the silo. The final conclusion – the crane can realize the task Fig. 5.2, the crane cannot realize (the object is too high) Fig. 5.3. Along the horizontal axis Ox, the horizontal radius is marked (in meters). Along the vertical axis Oy, the capacity is marked (in kN)

algebra system) applied in this procedure. The issue of a correct selection of cranes has been widely researched and discussed. The expert system for crane selection has been discussed by Warszawski (1990), whereas Lennerts and Kraus (1992) researched ESBE system and Kuo-Liang, Haas (1996) dealt with COPE system for the optimal use of cranes and Ali *et al.* (2005) presented employed a new approach for automated path planning of cooperative crane manipulators using a genetic algorithm.

The result of the working of the acceptance of crane module has been shown on Fig. 5. Two cases are shown on the graph presented in this figure. The first concerns the case when the system has accepted the crane, and the other when the system has rejected the crane in a specific case.

Visualisation of calculations results is displayed in a user friendly format, similar to the form used in traditional designing.

3.1. Dynamic visualisation

The SiCE module presents dynamic visualisation of co-operation of main elements of the sub-process described. At the same time, different states of particular elements of a system are presented, as well as changes in work progress. The screen displays, in symbolic time units, that is, “strokes”, how the construction proceeds. The system reports current aspects of all relations among all components, which allows for observation and analysis of all work phases. Three aspects are easily revealed: actions are sequential; they repeat in a technological cycle, some of them are carried out in a parallel manner.

The layers, approximately 2 meters high, are created by numerous crane cycles (one layer requires many crane cycles in reality and many strokes in software. The layer is prepared in 24 hours. In order to create such a layer (concerned with the cycle of the movement of the slip form), many cycles of the concrete mixer, crane and working crews are required. The number of cycles and time cycle of each of these elements is different, which can be clearly seen on the pictures presented. Single cycles and layers are marked with different colours.

Fig. 6 presents typical phases of a process.

At the same moment, work of 3 main elements of this partial process is being presented.

Each of these elements can be in different states:

- States for concrete mixers (CM): production of concrete mix, container loading, waiting for a next container.
- States for a crane transporting a container (TB): loading a concrete mixture, transporting a loaded container, guiding a container, unloading a container, transporting an empty container.
- States for concreters, actions (CP): guiding a container, unloading a container, concrete mixture distribution, vibrating.

The following figures illustrate typical stages.

3.2. Linear diagram

Bottom part of the screen (Fig. 4) presents a result of work of main elements as a linear diagram. Changing relations among components are visible. Time values on the horizontal axis are expressed in strokes. A cyclical character of the process was illustrated explicitly. All operations repeat in a defined sequence, but they are not always the same. It was shown that as the height of a silo increased, some operations proceeded longer to accomplish, and some took place as long as earlier. In this case, however, work stoppages became longer. Work stoppages are marked with white rectangles. A scheme is

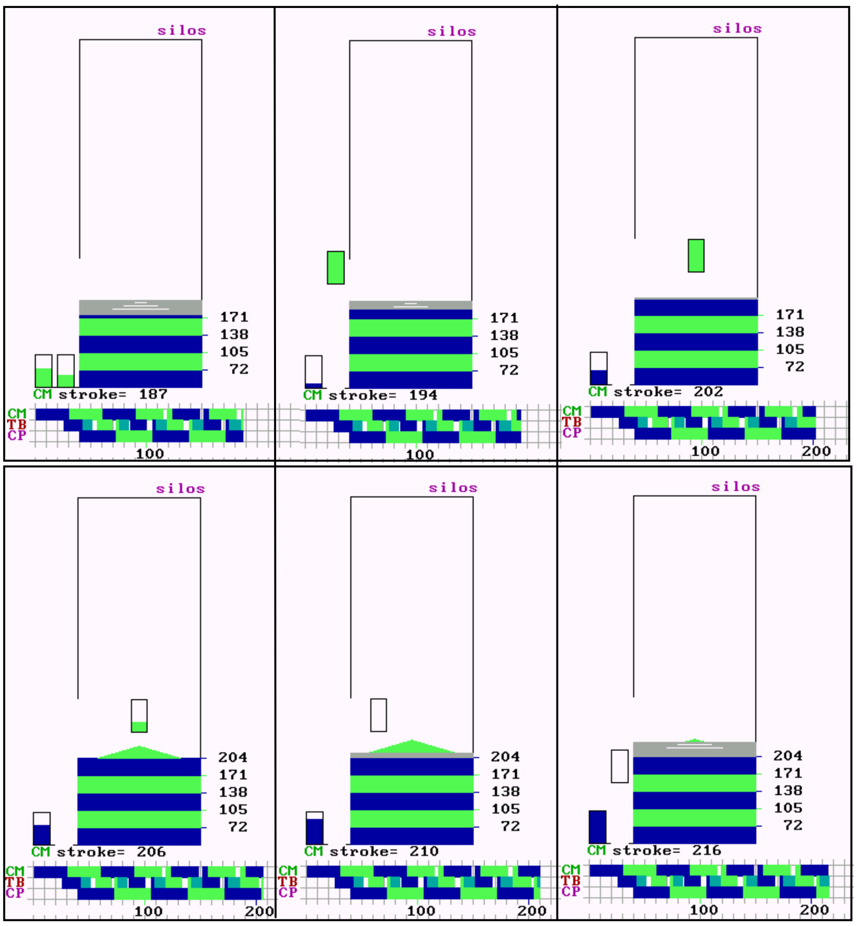


Fig. 6. Dynamic visualization – 6 typical phases of the process

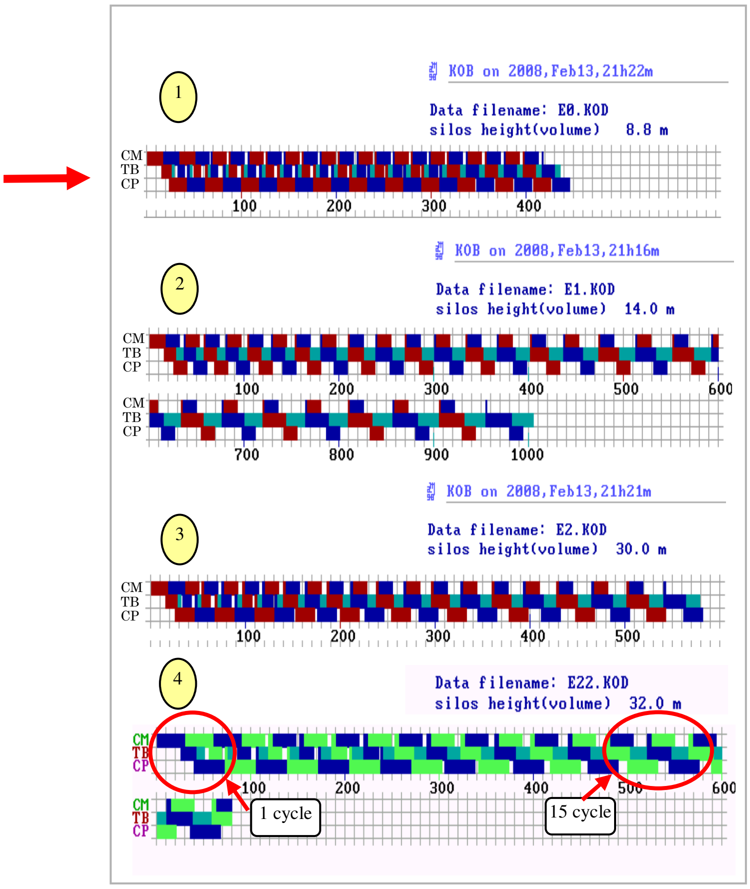


Fig. 7. Linear occupancy diagram describing changes in work cycles of system elements – 4 cases

updated dynamically, if any changes occur. Temporal dependences between presented elements (CM, TB and CP) are different for subsequent stages.

In real conditions of realization, such detailed observation and such exact results would be impossible.

Linear diagram in Fig. 7 presents results of a simulation for 4 different sets of production systems. In all cases, elements were combined into production systems with the assumption that during the whole process of realization, production means and work groups will remain unchanged. However, each of the cases analyzed had different parameters of machines used and different groups of workers (different number of workers). This module is useful for explaining the results of using different types of equipments and crews for currently being tested production set. Periods of full harmony of all elements as well as any disorders can be observed. Thanks to visualization, it is possible to indicate, when exactly disorders occur. It is easy to notice that on graph 7.4 the first cycle is significantly shorter than the 15th.

3.3. Data collected in results files

When the simulation is completed, the report in a form of diagram is displayed (Fig. 8).

A report of usage of particular elements in co-operation is displayed on a screen, and values are saved in different files. Results are saved in KOR, KOP, and KOQ files, then the program uses this information, carries out more advanced analyses, and visualizes relations between elements. Information received concerns, for instance, daily values of efficiency on particular heights of a construction, time needed to accomplish a task, work time usage of all elements of a system in percentages.

Temporal dependences between presented elements (CM, TB, CP) are different for subsequent stages (see relations on stage A and B on Fig. 8).

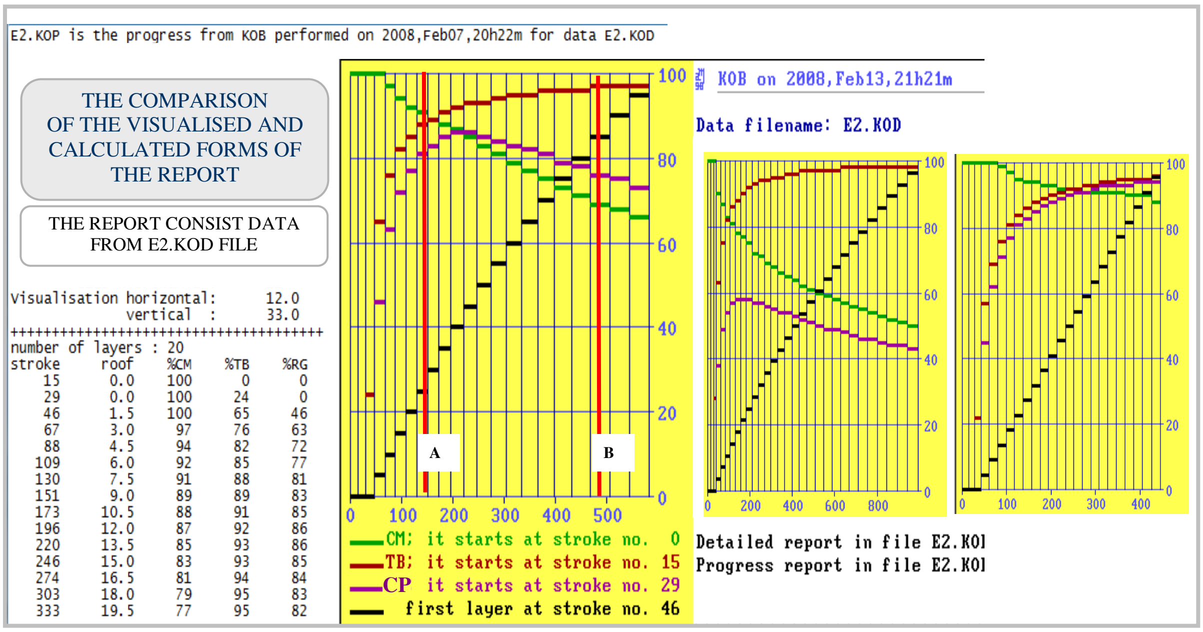
Simulation of the examples on Fig. 7 and 8 has been conducted on the basis of the theoretical data in order to reveal a diversity of variants.

A tendency of changes can be explained by means of a sub-model in Fig. 9.

Fig. 9 presents model of a situation, when for a certain height of a construction, a particular group of workers was selected so that a full harmonization of elements co-operated can be achieved.

Since with the increase of the construction, a cycle of work for the crane increases simultaneously, therefore, the number of workers should be decreased in order to avoid unnecessary work stoppages (see Fig. 9b). The assumption of the cases discussed was that during the whole time of construction works a set of elements will remain unchanged. This is why the higher the works are carried out, the lower the efficiency results.

The above considerations of 3 elements of the set (concrete mixer, crane and buckets, crew) have been presented on the basis of the working of one crane SiCE module). The working operations and module simulation, when a few cranes are applied, will be discussed below.



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E2.KOP is the progress from KOB performed on 2008,Feb07,20h22m for data E2.KOD
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THE COMPARISON OF THE VISUALISED AND CALCULATED FORMS OF THE REPORT

THE REPORT CONSIST DATA FROM E2.KOD FILE

```
Visualisation horizontal:      12.0
              vertical  :      33.0
+++++++++++++++++++++++++++++++++++++
number of layers : 20
stroke      roof     %CM     %TB     %RG
    15       0.0     100       0       0
    29       0.0     100      24       0
    46       1.5     100      65      46
    67       3.0      97      76      63
    88       4.5      94      82      72
   109       6.0      92      85      77
   130       7.5      91      88      81
   151       9.0      89      89      83
   173      10.5      88      91      85
   196      12.0      87      92      86
   220      13.5      85      93      86
   246      15.0      83      93      85
   274      16.5      81      94      84
   303      18.0      79      95      83
   333      19.5      77      95      82
```

```
CM; it starts at stroke no.  0
TB; it starts at stroke no. 15
CP  it starts at stroke no. 29
  first layer at stroke no. 46
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KOB on 2008,Feb13,21h21m

Data filename: E2.KOD

Detailed report in file E2.K01
Progress report in file E2.K01
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Fig. 8. Percentage of occupancies of absolute engagement of all co-operating elements CM, TB, CP (Oy axis) versus the strokes (Oy axis). Parameters from data file E2.KOD. The comparison of the visualized and calculated forms of the report

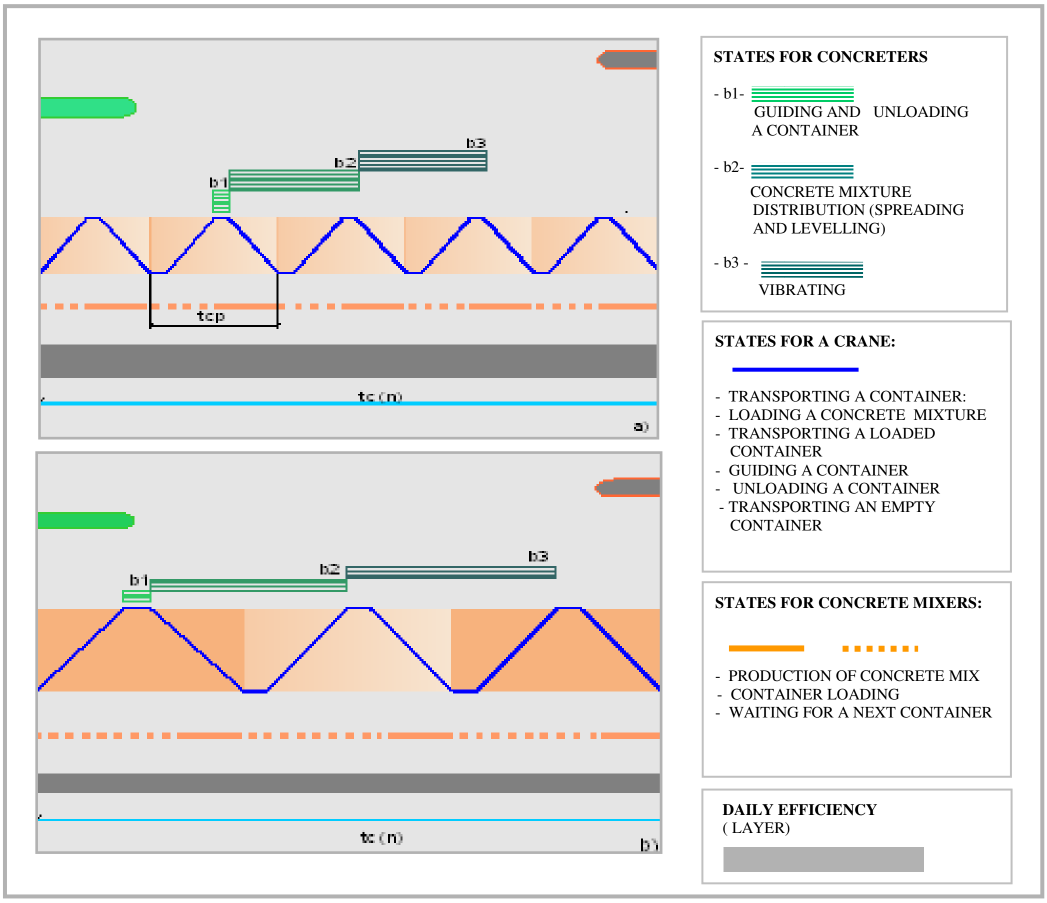

Fig. 9. A sub-model illustrating changes between particular elements of a system, when the height of a construction increases: b1 – guiding and unloading a container, b2 – concrete mixture distribution (the spreading and levelling), b3 – vibrating. Submodel shows the working of the concrete placers. Time has been marked on the Ox axis. The blue line shows changes of the length of the crane cycle

4. Combination of co-operating machines and groups of workers

The CoCE module allows for combining machines and groups of workers into production sets on a basis of decision-maker's preferences. By using information saved in the system, the module generates appropriate sets and simulates behaviour of sets created.

A particular procedure defines a number of cranes, concrete mixers, and workers needed to have a fully harmonized production set. The relations are unique, but not simple, as shown in Fig. 10.

Fig. 10 presents the visualization of results, i.e. the change of number of elements (concrete mixers, cranes, buckets) for subsequent stages of the construction process, when the constant level of efficiency is required. Fig. 10.1 presents a set combined in accordance with the following assumptions: work of leading and auxiliary production means and work groups must be uninterrupted. In order to meet the requirements, at a height of 33.2 m to 89.4 m, a second crane had to be used. Above this height, 3 cranes had to be used (Fig. 10.1). Fig. 10.2 illustrates the action of the module, when one crane is applied.

The CoCE module generates numerous solutions (sets of machines and gangs) ensuring a continuous work of several elements. Thanks to this, the situation can be constantly monitored at various stages and compared to more or less advantageous variants.

In order to reveal analytical capabilities of the system, screen printouts for 3 different cases are presented in Fig. 11. An influence of a change in a number of cranes (a crane is a leading machine) on efficiency of a production system are observed. The task is to combine elements in such a way that the greatest harmonization possible is achieved.

There are cases where the cooperation of elements is a crucial moment affecting the result (economical aspects are not taken into account). Fig. 11.2 presents a model meeting the requirements; an uninterrupted work of all elements is observed. In this case, a second and third crane had to be used. In the first case (Fig. 11.1) it was clear that only one crane caused long work stoppages in concreters' work. The third case illustrates a situation, in which 3 cranes work together from the beginning. Dark blocks show a loss of working time due to too many cranes used.

All examples discussed were presented on a basis of theoretical values. However, they sufficiently illustrate tendencies and precisely show working of the inference mechanism for the CoCE module. Rectangles on the left-hand side of a screen show a change in time of a system cycle. Fig. 11 visualizes several variants of the production sets and considers changes taking place during the realization process. It is worth emphasizing that this visualized user friendly formula is reflected by the module presented in Fig. 9.

5. Conclusions

To sum up issues discussed in this article some conclusions can be made pertaining to research findings of a particular case, and some broader implications can be formulated in reference to modelling, simulation and visualization of the construction and expert system.

This article discussed the work of the modules SiCe and CoCE as a particular case. The research was to explore the influence of changing conditions on the efficiency of the production cycle. The analysis has been conducted for the silos construction by the monolithic technology. This article discussed the working of the modules SiCe and CoCE in a particular case. The aim of the research was to explore the influence of the changing conditions on the efficiency of the production cycle. The analysis has been conducted for the silos construction in the monolithic technology. The working of the module SiCe has revealed that by employing the same production resources, when the construction raises, the efficiency gradually decreases. The working of the CoCE module has shown how this obstacle can be eliminated. A correct number of machines has been introduced into the construction process (in this case the number has been increased) in order to secure a constant level of efficiency. As a result, a harmonization of all machines and working

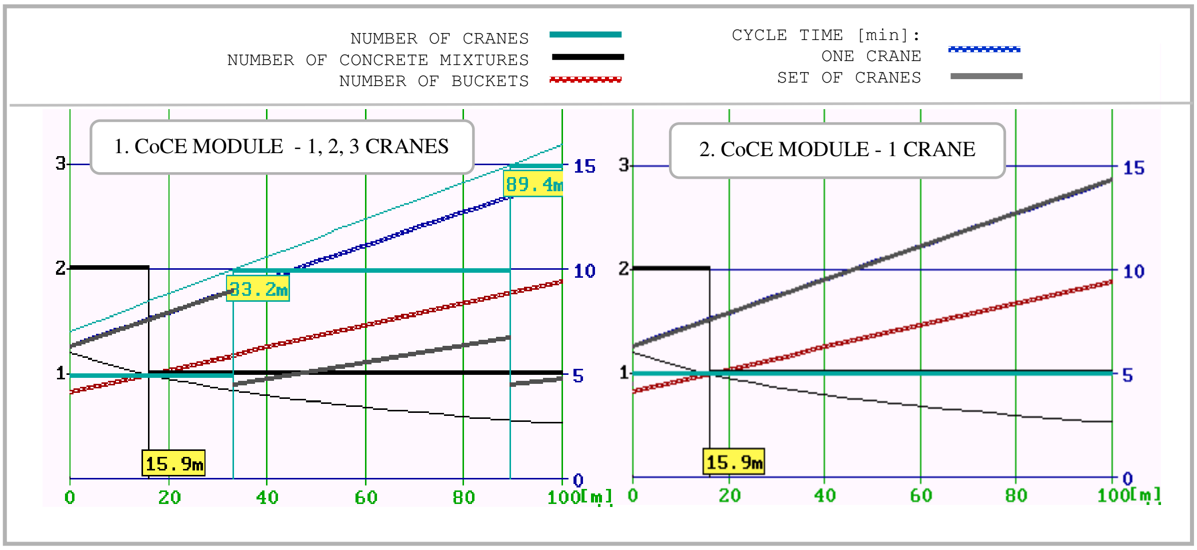

Fig. 10. An example of simulation of different sets of elements

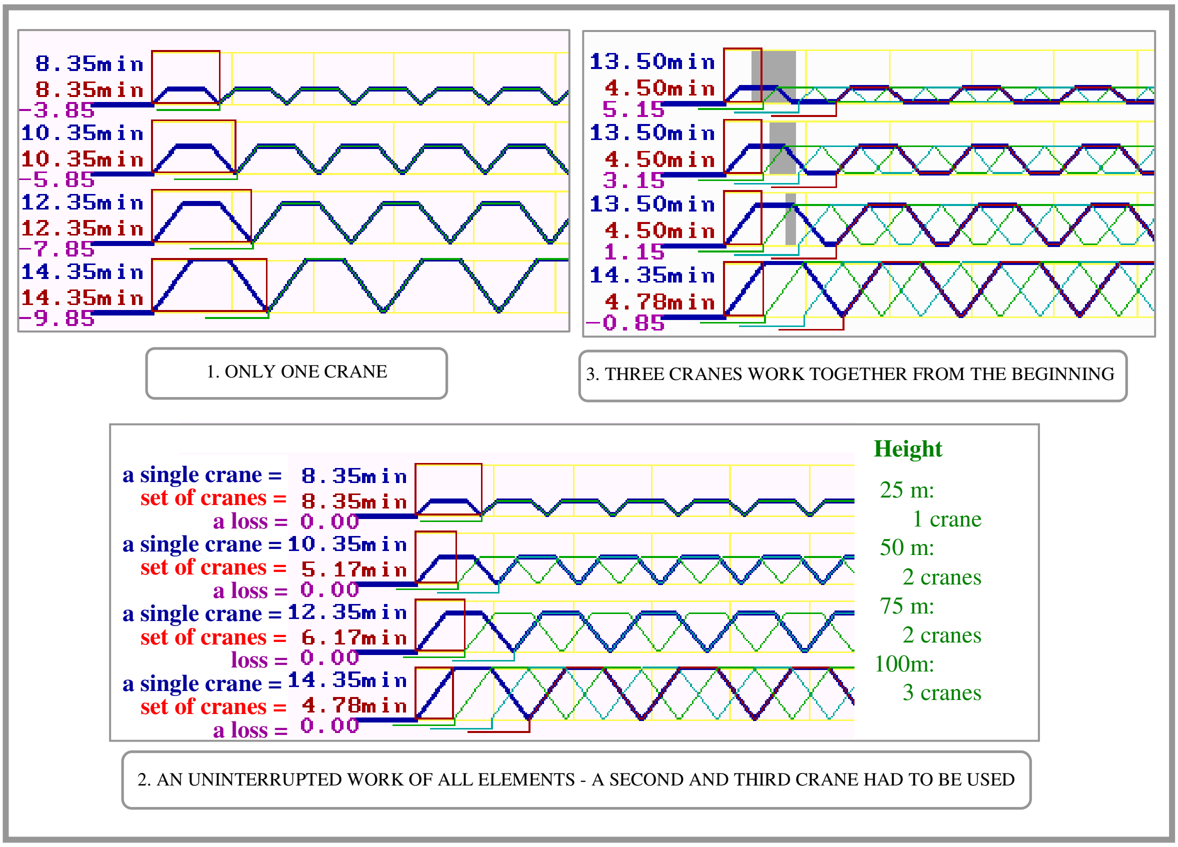

Fig. 11. An example of simulation of different sets of elements

sets has been obtained. A capability of carrying out work simulations designed in accordance with particular criteria reveals indiscernible in practice the correlation between all elements.

Advantages and benefits achieved by employing simulation and visualizations techniques provide an in-depth insight into complex construction processes. The simulation and calculations improve construction process planning by organizing the resources for maximum productivity and prepare well-harmonized production sets. This computational analysis demonstrates that by employing improved analytical tools the construction processes can be considered in a way which could not be achieved by means of traditional methods.

Visualization of simulation results makes it easier to understand the complexities of construction processes by taking into account their dynamic character. Visualisation of the results obtained also facilitates communication between all participants of the undertaking. In addition, a significant advantage is achieved by obtaining reports concerning each element in every phase of the process. Furthermore, presented visualization modules can be used as very effective tools for educational training in construction process design thanks to their user friendly formula. Developing a satisfying model of the process requires a detailed analysis and a very precise description of the phenomenon. Creating models and then software result is enriching the knowledge of the domain, since new facts and relations are revealed, which are indiscernible by traditional design tools.

Modules of the presented expert system illustrate that this is a modern device for technology designing and work organization. The modelling, simulation and computational analyses demonstrate a great value of the developed system for the complex cyclic construction processes. The system designs monolithic constructions in many aspects such as: selecting sets of machines, detailed analysis of work carried out by work groups, making schedules, and multi-criterion analysis. This article presented only some capabilities of an expert system, which is still under development.

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SUMODELIUOTO MONOLITINIŲ STATYBŲ PROCESO VIZUALIZAVIMAS

M. Hajdasz

Santrauka

Nagrinėjamas sumodeliuoto statybų proceso vizualizavimas naudojant du modelius, kurie yra ekspertinės sistemos dalis. Statybos procesų modeliavimas ir analizavimas, pasitelkiant modeliavimo ir vizualizavimo rezultatus, leidžia pateikti dalyviams nuodugnų šio sudėtingo sumanymo supratimą. Aptariama ekspertinė sistema turi hierarchinę ir agreguotą struktūrą ir yra sukurta specialiai monolitinėms konstrukcijoms. Pagrindiniai šios sistemos elementai: betono maišyklės, kibirai, klojiniai, kranai ir statybos brigados. Šis straipsnis apibūdina dviejų modulių darbą, kuris leidžia suderinti gamybos sistemos priemonių, modeliavimo ir vizualizavimo rezultatus. Modeliavimas yra naudingas įrankis analizuojant statybos procesus, nes leidžia statybos projektuotojams atlikti eksperimentus, kurių metu įvertinamos įvairių variantų įgyvendinimo galimybės. Vizualizavimu išsamiai paaiškinama, kas yra statybos proceso sudėtingumas. Buvo atsižvelgta į dinaminę statybos proceso prigimtį, ir tai buvo išspręsta naudojant šią sistemą.

Reikšminiai žodžiai: statybų operacijos, monolitinių statybų procesai, ekspertinės sistemos, modeliavimas, modeliavimas ir vizualizavimas.

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