Quality assurance of construction processes

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Assurance de la qualité dans le processus de construction

Qualitätssicherung von Bauprozessen

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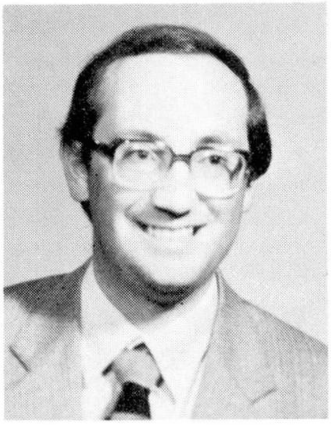

Čeněk Jarský, born 1953, got his MSc degree in Civil Engineering and the PhD degree in Technology of Structures at Czech Technical University of Prague. For five years he worked in building process modeling. Now he is responsible for research in reduction of energy consumption and costs in construction processes.

SUMMARY
The necessity of evaluating the quality in the course of the construction process itself, not only according to the resulting product, is discussed. Quality parameters of the course of the construction process are stated and a proposed mathematical model of different construction processes, which enables finding the optimal means of production for the process is shortly described. The influence of failures of machines on the quality parameters of the process is verified by help of the model on earthmoving works at the Gabčíkovo waterwork on the river Danube.

RESUME
Il est nécessaire de juger la qualité au cours du processus de construction, et non seulement son produit final. Les paramètres de qualité du processus sont décidés et le modèle mathématique des différents processus de construction est décrit brièvement. Ce modèle applique la simulation stochastique et permet de trouver les meilleurs moyens de production. L'influence des pannes de machines sur les paramètres de qualité du processus est contrôlée à l'aide du modèle de chargement et transport de matériaux pierreux dans l'ouvrage hydraulique Gabčíkovo sur la Danube.

ZUSAMMENFASSUNG
Die Notwendigkeit, die Qualität des Bauprozesses nicht nur nach seinem endgültigen Produkt, sondern auch nach seinem Verlauf zu beurteilen, wird diskutiert. Weiter werden die qualitativen Parameter des Bauprozesses bestimmt und kurz das auf der stochastischen Simulation basierende mathematische Modell von verschiedenen Bauprozessen beschrieben. Dieses Modell ermöglicht die optimalen Erzeugungsmittel für den Bauprozess zu finden. Mit Hilfe des mathematischen Modelles wurde der Einfluss der Betriebsstörungen bei Baumaschinen auf die qualitativen Parameter der Erdarbeiten für das Wasserwerk Gabčíkovo an der Donau bewiesen.

1. INTRODUCTION

This article would like to respond especially to the papers /9/ and /1/ written in the Introductory Notes to the workshop. Let us introduce that by the term of a construction process we shall understand a certain type of activity done by a work gang on the building site using certain means of production (e. g. machines, tools etc.) with a certain distribution of labour within the work gang, e. g. earthmoving works, concrete laying works etc.

In /9/ a definition of the quality of a technical facility is given in the relation to its user. The definition of the quality stated in /1/ looks to be more complex as well as more abstract. In accordance to both definitions the quality of a building process is evaluated according to the quality of the resulting product (a building, a construction, a construction unit etc.) as it has been traditional since. One has to realize that a product of a high quality can be produced by a process of a very low quality of its course, that means with a low productivity of labour, with a high consumption of labour and costs and with a low utilization of means of production. On the other hand it is possible to produce a product of a poor quality to its user and to gain relatively good levels of economical indexes (low labour consumption, high utilization of machines, short time of construction etc.) what means a good quality of the course of the process.

In order to assure the quality in all phases of the building process it is necessary to judge its quality not only according to the quality of the resulting product but according to the course of the construction processes, too. Construction processes should therefore have a course of a good economical level with a high productivity of labour and high utilization of means of production and the resulting product should achieve the requested quality demands.

A mathematical model capable of simulation of different construction processes on a computer was created by the author in /5/ for the evaluation of the indicators of the quality of the course of construction processes. The indicators are stated further on. The proposed model enables to synthetize (simulate) and then analyze the actual course of different construction processes (e. g. earthmoving works, concrete laying works, assembly of pannels and others) on building sites inclusive random factors and influences (e. g. traffic conditions, failures of machinery, people factor etc.). Utility of use of the Monte Carlo method /2/ chosen for the modelling has been discuses in the survey /3/. This method enables to valuate the reality on the building site much better than classical deterministic methods of design of the means of production in a construction process or the queuing theory which is sometimes used too, see e. g. /8/.

The main purpose of the proposed model is the optimization of the quality parameters of the course of the construction process based on the choice of the best variant of machinery or work gangs that can be used in the process.

2. QUALITY PARAMETERS OF THE COURSE OF THE PROCESS

The evaluation and the choice of the best variant of the process is carried out according to 10 technological, technical and economical indicators, proposed in the report /4/, that formulate the requirements on the quality of the course of the process. One complex utility function for the evaluation was not used because usually only one parameter is crucial for the contractor in accordance to his resources and possibilities.

The technological parameters are as follows:
- total time of the process,
- output per time unit,

- utilization of machines,
- total labour consumption (machinetime),
- actual labour consumption (machinetime) per measure unit of the product.

The technical parameters are:
- total energy consumption in the process,
- energy consumption per measure unit of the product.

The economical parameters are:
- total costs,
- costs per measure unit of the product,
- productivity of labour.

All quantities that characterize the parameters stated are to be mathematically expressed and calculated in the analysis of the simulated variant of the building process.

3. A FEW FACTS ABOUT THE MODEL OF CONSTRUCTION PROCESSES

3.1 Fundamental assumptions and conditions of calculation

On building sites situations very often occur where one equipment (e. g. a loader) attends an another equipment (e. g. dumptrucks) and creates a so called mass operation process. It is intuitively clear that the design of both equipments has to be in harmony, that overdimensioning and then a small utilization of the serving equipment is connected with high costs and output losses in operation of such a system. Mass operation processes (sometimes named as queuing processes) can be characterized as flowing processes influenced by random interference. Because of this interference, sometimes queues may occur before the channels of service (e. g. loaders), sometimes channels of service may not work, because no units (e. g. dumptrucks) are available. There are more stages (phases) of service in such a process usually, sometimes more parallel channels of service in one phase are used. A circular (closed) system representing earthmoving works with 4 phases of service in line (1st phase - 2 parallel loaders, 2nd phase - road, 3rd phase - 2 parallel places of dumping, 4th phase - road back) is illustrated on fig. 1, an open system is on fig. 2. The stochastic simulation using Monte Carlo method was chosen for the evaluation and judgement of similar systems as it was stated previously.

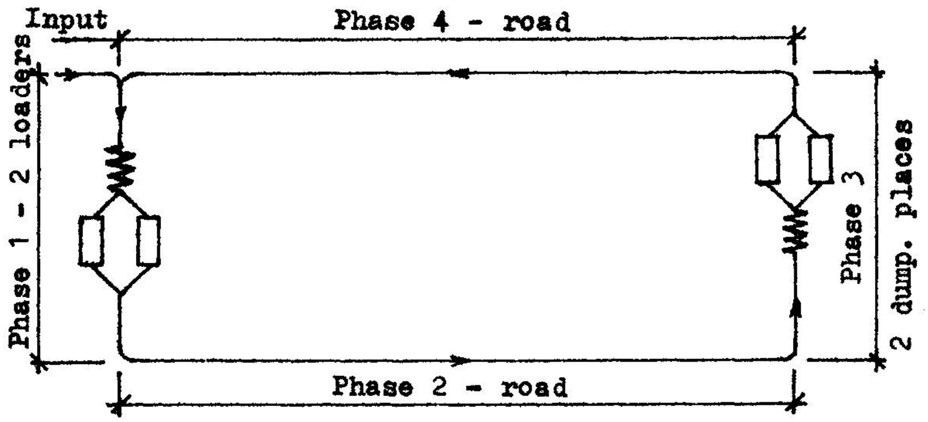

Fig. 1 Example of a closed mass operation system

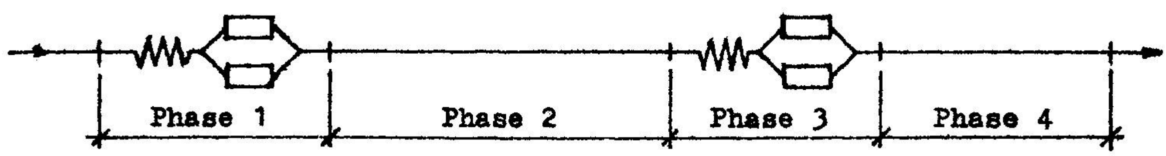

Fig. 2 Example of an open mass operation system

The mathematical model of a building process simulates a circular (fig. 1) or an open (fig. 2) system with which the construction process can be described. Multiple use of the model enables the simulation of more difficult systems, having a combination of a circular and an open system. The main part of the model is the time synthesis and the following analysis of the process. The random quantity is the actual service time in the channel (e. g. filling of a dumptruck by an excavator, time of driving through the road etc.), which is generated by a random number generator in the requested probability distribution.

If the channel of service is being repaired it cannot be used for attending the units, it is therefore blocked, units have to wait or use the other parallel channel if it exists. Repair of the unit does not block any channel of service.

Two sorts of phases of service are considered. The first sort are actual machines (e. g. excavators, loaders, concrete plants etc.) which are capable of serving only 1 unit during a certain time period. The other sort are roads where more units can be in during a certain time period.

The flowchart of the mathematical model was published e. g. in /4/ or /6/.

3.2 Simulation of failures and repairs of the machines

The proposed model simulates random failures of machinery (units and channels of service). The chance of failure or probability of a failure EPS is read by the computer in the data file for every machine (e. g. 0.01). In the failure control section of the program a random number XI with the rectangular distribution in the (0; 1) interval is generated. If the condition (1)

$$EPS \geq XI \qquad (1)$$

is fulfilled a failure of machinery occurs and the time of repair is then generated, using the exponential probability distribution. The average time of repair is gained from the data file. The machine is blocked for use during the time of its repair. For units, the time of repair TRU(h, i, j) is added to the time arrival of the unit i into the phase j in the h-th round TINP(h, i, j) and the unit is marked that it was being repaired. In case of the channel of service repairs, the time of repair TR is added to the value TOUT1(j, k) which means the time when the channel k in the phase j will be free and prepared to attend the next unit. By this addition the channel is blocked for the time TR as well.

4. VERIFICATION OF THE INFLUENCE OF FAILURES OF THE MACHINES ON THE QUALITY PARAMETERS OF THE CONSTRUCTION PROCESS

The model was recently used for the optimization of loading and trasport of gravel for the embankments of the waterwork Gabčíkovo on the river Danube. The scheme of this process responds to fig. 1 with the exception of the 3rd phase where no queue was created. There were 3 different resources of gravel on site and 17 places of consumption - 17 sections of the embankments of the lenght 1 km each. Many different variants of the process were simulated on the computer using different sorts and numbers of machines. The optimum according to the costs and fuel consumption was to use the UNC-200 loaders and Tatra T 148 S1 dumptrucks of Czechoslovak production in certain numbers for different sections, quoted in table 1. In this table the basic characteristics (costs and fuel consumption per measure unit - m^3 of gravel) of the process are compared in case of the process with random failures of machinery and in case of the trouble-free course of the process. The chance of failure for the loaders was 0.01, for dumptrucks 0.02. The average quantities were calculated according to the ammount of gravel to be transported

Section km	Machinery used: number of loaders / number of trucks	Trouble-free course of the process: costs Kčs/m^3	Trouble-free course of the process: fuel consumption l/m^3	Course with failures of machines: costs Kčs/m^3	Course with failures of machines: fuel consumption l/m^3
1	1 / 10	3.46	0.80	10.44	1.72
4	1 / 6	2.28	0.45	2.26	0.44
6	1 / 8	2.95	0.64	3.82	0.64
7	2 / 8	2.25	0.39	2.91	0.41
9	2 / 16	3.17	0.69	5.54	0.86
11	2 / 30	4.15	1.00	6.72	1.52
12	2 / 42	5.33	1.35	8.54	1.98
15	2 / 28	3.80	0.90	4.95	1.04
17	2 / 14	2.61	0.53	6.09	0.49
Average		3.40	0.77	5.64	1.00
Increase %				65.88	29.87

Table 1 Characteristics of the process

from the resources to the sections of the waterwork.

It is to be seen that the influence of failures of the machines on the quality parameters of the process is surprisingly high, the costs being increased for 66 % and the energy consumption for 30 %. It is to be considered from that fact that it is worth to have at least 1 dumptruck on the site more which can be used in case of failure of a machine. Thus a trouble-free course of the process can be ensured with a minimum increase of cost and fuel consumption. Other examples were published in /6/ and /7/.

5. CONCLUSIONS

Mathematical stochastic models have gained more and more significance in the construction process research recently. From the results which have been obtained so far by use of the proposed model is to be seen that this model is suitable for simulation of many types of construction processes. The results gained by the model approaches the reality of the process more than if they were calculated by using the traditional deterministic way or the queuing theory. It is useful for calculating of quality parameters of different variants of the process for gaining the optimum. Those parameters should be judged extra of the quality parameters of the resulting product in order to assure the quality of all phases of the building process, the phase of production of the structure inclusive. The model is capable to research the influence of different factors on the quality indicators of the course of the process (e. g. failures of the machinery, number of means of production etc).

Further research in this field will be directed to obtaining more reliable statistical data for the input for the model (chance of failure of machines, time monitoring of the behaviour of similar systems etc.) and the model itself is planned to be improved by capability to simulate construction processes which consist of more than one circular system with certain points of contact among them.

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