On an Expert System for Building Process Modelling and Control

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Summary

The submitted contribution describes the main principles and results of the CONTEC® integrated project bidding, planning, management and quality control system developed in the last years. This computer expert system is based on modeling of the building process of erection and the process of management and maintenance of different structures by use of network diagrams created by an original construction technology network diagram method. This method enables to create and then to use besides classical network graphs different typical network diagrams as models of erection, behavior and maintenance of buildings. Resulting documents describe not only the resulting price, but also the optimum construction or maintenance flow, the cash and resource flow and the quality assurance question.

Keywords: construction technology, building process, maintenance, network analysis, mathematical model, project management, planning, quality assurance, network diagram, computer expert systems.

1. Introduction

When new projects have to be undertaken it is necessary to visualize all the operations of the projects, arrange these operations in their proper sequence, achieve confidence that every participant of the building process (the owner, the architect and the contractor) understands each of his tasks, acquires the know-how and means necessary to perform them and feels convinced that the method chosen for performing all tasks is the most progressive and economical. Thus all projects have to be efficiently planned at the investor's (owner's), architect's and contractor's sides. In the planning and design stage of the project several specific problems must be solved and many points of view have to be taken into this decision process. A lot of these questions can be efficiently solved by creating of a computer model of the flow of the building process of the structure. The model must be based on the construction technology analysis and must reflect all architectural, technical, technological and economical links of the building process.

The market conditions in building industry force every contractor to be able to react very quickly while making his bid to the requests of the investor for getting the order. Therefore the contractor must have means that are capable to create the basic documents of the bid, e. g. price and technology analysis, time schedule of the proposed building process, selection of basic means of production (machines, labor) etc. The linkage to the quality assurance system appears here even in the first stage of planning of the project [2]. It is desirable to be able to make use of the documents made during the bidding process further for actual management of construction processes on site and for quality assurance of the whole project. To make such evaluations as precise and quick as possible an expert computer based project planning and management system has been developed, which is capable to model very quickly not only the building process of the project itself, but simultaneously the process of maintenance [8], and reconstruction [9], [10] needed in the years to come, or even the process of demolition if need be.

2. Requirements on the model of the building process

The feasibility study of the owner must answer some main questions, among others especially what the price of the project will be, what the time schedule and flow of the building process will be and whether it is possible to keep the required deadline of the project from the technological point of view. The total desired time of service and the quality level has to be stated too. It is desirable for the investor to have the possibility to model even some contractor's data about the building process of the project [7], especially what the actual cost for the project will be and therefore the resulting profit, how many craftsmen in special professions are necessary, what sorts of machinery and when they are needed on site, how the cash flow and finances will be secured in proper terms and how the quality of the project and its parts will be assured. Questions which has to be answered by the contractor while creating the bid are very similar.

With the help of the CONTEC® system the user has the possibility to simulate the proposed time and resource flow of the building process of the project on a microcomputer even if the topical relevant data about the project in the planning stage are very poor. The more precisely the task is determined, the better results can be obtained from the model. After completing the model the user can make his decisions about actual resource allocation in time according to the whole time of service (including the influence of inflation) and prospective maintenance and reconstruction. On the other hand after completing the model the contractor can make his decisions about actual resource allocation in time according to the whole production program of his firm. This is relevant especially for finances, costs, craftsmen, machines, material etc. The model of the building process is based on the main documents of the construction technology design, including quality assurance checklists [4], [5]. These documents are usually accompanied by the modeled cost estimations transferred into the form of the budget. This way of modeling brings the project management concepts into action.

3. On methodology and basic documents of the construction technology design

The main documents in construction technology design include files of technological standards, sometimes called as technological analysis sheets, and network diagrams. The close link between these documents which is used in the CONTEC® expert system enables to elaborate bar charts, line-of-balance graphs, allocation graphs of different technological and economical resources and quality assurance checklists. Hitherto the said documents, on one hand technological standards and on the other hand network diagrams were mostly processed subsequently, separately. Their close construction technology relationship was often disregarded and network diagrams elaborated without consistent technological analysis and synthesis contained a number of errors which made them useless for construction project control. Quality assurance checklists were usually not elaborated at all or by a separate division with no connection to the actual flow of the building process. The simultaneous elaborating of technological standards, network diagrams and quality assurance checklists used in the CONTEC® expert system eliminates the processing of network diagrams without the technological analysis and synthesis and makes possible to use the close link between technological standards and documents for quality management in the project.

The technological standard (program) determines the technological structure of the production process (sequence of construction processes, volume of production, labor and cost consumption, number and profession of workers or machines etc.). According to the calculated network diagram the technological standard contents a bar chart which indicates the time structure of the production process. Further a technological scheme showing the spatial structure of the process is usually added. The connection between the time structure and the spatial structure of the building process can be seen in the line-of-balance graph. The quality assurance checklist which is automatically simultaneously created consists of instructions for performing the quality check of main features of the resulting product at every significant construction process.

According to the values of the duration of the processes and the minimum working space necessary it is possible to determine (with regard to the direction of the course of processes) the critical approximation of construction processes and to link these processes immediately in the optimum way in the construction technology network diagram method. Thus all documents mentioned above after the network diagram calculation depict floats of the construction processes.

4. Basic fact on links in the construction technology network analysis method

The CONTEC® network analysis method used by the expert system is determined for simultaneous evaluating of technological standards and network diagrams and for the optimization of linking the construction processes from the point of view of maximum use of minimum working space on site necessary for the efficient, economical and safe performing of construction processes including technological pauses [3], [5], [6]. The CONTEC® network analysis method uses the activity-on-node network diagram. All four types of links of activities introduced in the precedence graph method (finish - start, start - start, critical approach and finish - finish), [1], [6], are included in the CONTEC® method too. The main disadvantage of the precedence graph method is the necessity to know the actual values of lag times between every two activities that are linked together and their duration while creating the network diagram. This would make the concurrent evaluation of the technological standard and of the network impossible.

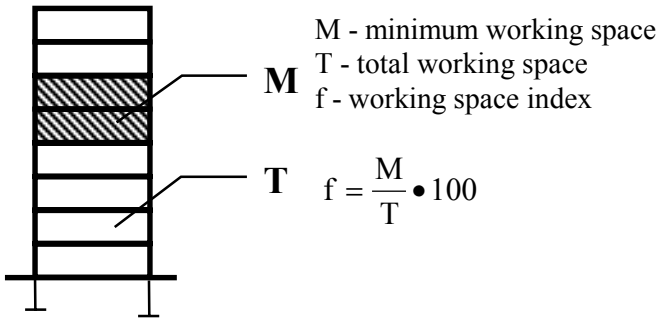

Fig. 1 Working space index

Therefore the construction technology network analysis method introduces the 5th type of link, the construction technology link, that results from the condition of release of the minimum working space on a structure by the previous work gang so that the following work gang could start as soon as possible. The lag time is not given by a certain time value but it is calculated by the computer according to the duration of linked activities and to the spatial structure of the building, which is represented by a working space index f. This index is determined by the ratio of the minimum working space needed for the gang divided by the total working space in the building, e. g. in a 8 story administrative building the usual minimum working space are 2 floors, so the working space index f is 2/8, that is 25 %, see figure 1.

Introducing this link in the CONTEC® method means not only a simplification of inputting the data of the network diagram but it permits a wide formation and utilization of typical network diagrams as computer files for the erection, maintenance and reconstruction of different sorts of buildings with the possibility of their modification according to the spatial structure of the actual building. There are usually only three main types of working space for different activities on site (f_1 for subterrain structure or works on the roof, f_2 for erection and plumbing, f_3 for finishing works). Thus only three values of the main working space indexes are sufficient to evaluate all technological constraints in the building process. In the typical network diagram the values of the working space indices are given parametrically. While stating data about the actual building the typical network diagram can be modified from the point of view of the spatial structure of the building process by stating of the 3 main working space indexes only. After calculation of such network diagram the early and late terms of activities are stated so that the working spaces for work gangs which are defined by the minimum working space indices are free.

Further, the CONTEC® network analysis method introduces the 6th type of link, the flow link, that results from the condition of continuous course of a construction process on different products, e. g. sections, buildings etc. The 7th and 8th types of link, the partial links, describe the condition that a following activity can start (or must finish) after the completion of a certain part of the previous activity or vice versa. These links are determined by the partial link indexes that represent the ratio of the duration of finished part of the previous activity divided by the total duration of the previous activity (type 7) or the ratio of the duration of unfinished part of the following process divided by the total duration of the following process (type 8). If this index is negative it represents the same ratio but for the following (type 7) or preceding (type 8) activity. Using the flow link modified typical network diagrams or evaluated network diagrams of buildings can be automatically linked into a greater network that may represent the building process of the whole project consisting of more buildings, e. g. an industrial plant, or its maintenance or reconstruction. In this case the flow links are generated by the system at activities that are performed by specialized work gangs that proceed continuously from one building to another. The network diagram can be calculated on the deterministic or stochastic base, [6], [7], without or with respecting the random influences.

5. Way of quick expertise of the building process

The main condition for modeling the erection, maintenance and reconstruction process is stating the task and intentions of the investor. Sometimes the investor has only very approximate imaginations what he wants to be built. He has some propositions and drafts about the layout and about the construction system. Later the investor usually has a certain level of design of the project including the bill of quantities which is very significant.

Besides the files of typical network diagrams a database for the quick expertise of the building process is available. This database consists of the main data about all construction processes that may occur. It includes main facts about time standard, productivity of labor, price of the product, number of workers, technological pause and other 20 economical and technological resources (costs, wages, average profit, machines, materials, professions etc. For elaborating of the quality assurance checklists another database of the checks of the quality of resulting products (what must be controlled, in which way, according to which standards etc.) was created. The quality control database is closely linked with the database of construction processes. Both databases are updated twice a year.

The typical network diagram of a building process as a computer file contains the data about the sequence of the construction processes and their linkage. It is preferable to use especially the construction technology link stated parametrically, because then the typical network diagrams can be easily modified according to the spatial structure of the actual building. The volume of production and price of all activities that are included too are related to an adequate custom-made measure unit, usually m^2 of build-up area. When the user simulates the building process he calls up in the very first stage the typical network diagram of the certain building, modifies it by stating the actual main working space indices and the computer generates the model. Thus, the user of the expert system can get the first model much quicker than by the use of classic project management systems. In case of reconstruction of buildings there is usually difficult to use the typical network diagram as it is, because each reconstruction process of a certain building is unique. The created model has to be defined with more precision according to the facts known about the building and the flow or the reconstruction process. If the bill of quantities is available its values can be automatically transferred into the model [7]. After the calculation of the network diagram the user gets the early and late terms of starts and finishes of all activities.

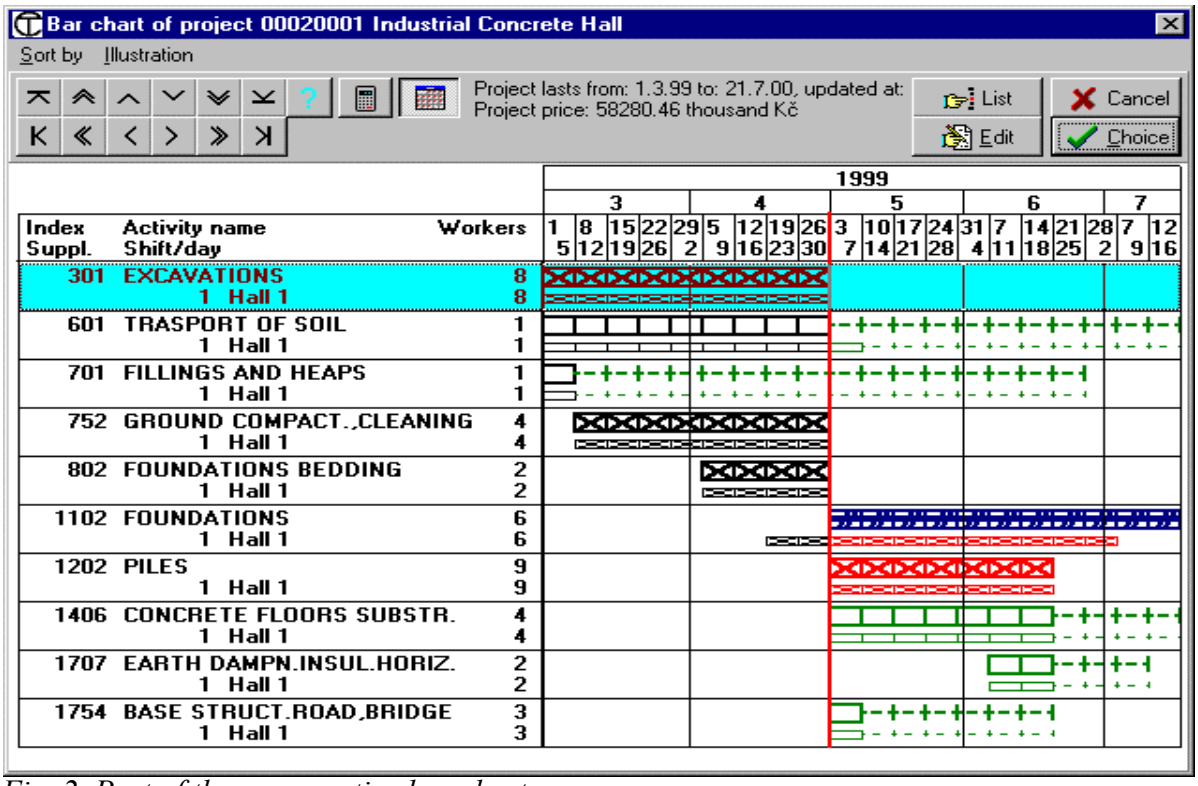

Fig. 2 Part of the comparative bar chart

The network can be automatically recalculated from the point of view of keeping the deadline of the project required. The user then gets the number of workers or machines that he needs to use in the construction processes. The system enables to print the calculated network diagram in different forms (technological standards, bar chart, line-of-production graph, resource allocation graphs of cash flow, labour consumption, need of work force etc.). Even in the very first stage of the plan it is possible to create the quality assurance checklist by the use of the database of quality checks. The particular network diagram can be then aggregated into the higher information level of technological stages, degrees of completion or to the level of buildings.

All documents that are gained on the base of the construction technology network graph can be easily updated according to the actual completion of construction processes on site at a certain term. If there is a delay, the system suggests what measures are to be done to be able to keep the final deadline of the project. At the same time it keeps the technological rules of the building process. This can be visualized in the comparative bar chart, where the updated version of the building process drawn in bigger lines is compared in one document with the planned flow of the process, see fig. 2. Critical activities are drawn in read, non-critical activities in green and delayed activities in blue. According to the recalculated network diagram the line-of-balance graph can be automatically drawn on the plotter. The outputs from the system are used for evaluation of operational plans on site and for operational registration with the link to the invoicing agenda. On the other hand, the operational registration files from the invoicing system can be used for automatic updating of the network diagram in the CONTEC® system and then recalculating the terms of activities and of the operational plan. A new resource allocation balance is the result of the updated model of the building process. Quality assurance checklists are updated simultaneously in similar way from the point of view of terms of quality checks.

6. Conclusions - examples of use on site

Fig. 3 Simulated view of the Zbraslav housing estate

The main documents of the construction technology analysis created in the mentioned way can contain the model of the building process of the project that includes all necessary data for the building process control and management and resource allocation balancing.

Nowadays the CONTEC® system linked with different cost estimation systems is used in more than 350 investor's and contractor's firms in Czech Republic and Slovakia. The described way of preparation and management of structures has been used for management of different significant projects in these countries and abroad, e. g. reconstruction of the Czech Parliament building, erection of the Temelín nuclear power plant, construction of the oil storage plant at Nelahozeves, reconstruction of the Prague City Hall and of the Toscano Palace, reconstruction of historical buildings around the Old Town Square and of the Hybernia Palace in Prague and many others.

One of the very interesting cases which was controlled by the CONTEC® system is the erection of a large housing estate near Prague which has been modelled from the very first stage of the feasibility study of the investor, through the bidding process for the contractor, till to the level of operational planning. The model has been regularly updated according the topical level of completion at certain time periods, see fig. 3 and 4. The finish of this project is planned in the year 2001 and its total costs are 1.4 billion CZK (about 47 mil. USD).

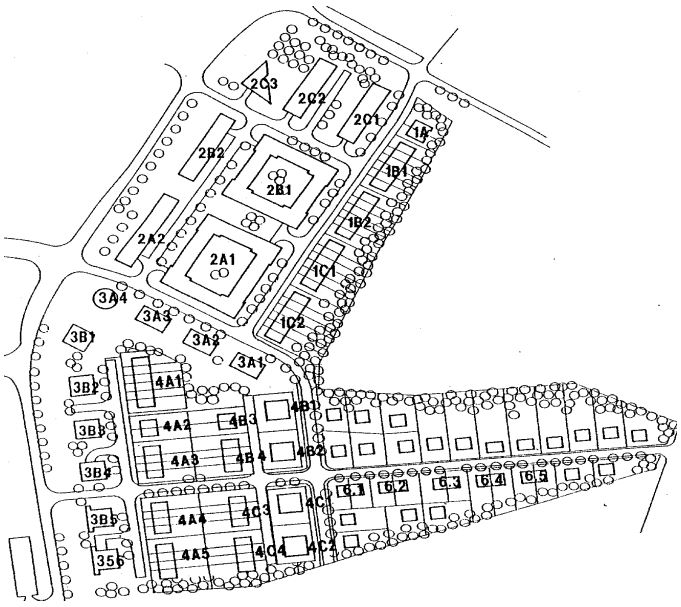

Fig. 4 Layout of Zbraslav Housing Estate

The system described can be used on IBM PC computers under Windows 95/98/NT operational system. It requires about 16 MB of RAM, colour printer and plotter are recommended. Nowadays the CONTEC® system linked with more than 15 different Czech and Slovak cost estimation systems is used in more than 350 investor's and contractor's firms in Czech Republic and Slovakia. It is very popular in firms that introduce the total quality management system according to the ISO 9002 as the quality assurance checklist creating is immediate after elaborating the model of the project. The experience from the users is very wide now and it is permanently used to the innovation of the system, nowadays especially in the field of operational and quality assurance record-keeping.

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