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Results using prt-nets for controlling complex building processes

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Abstract

The optimum control of a building project is the aim of the supervision of construction in a construction company. In order to get a real optimum control of the cooperation between man, machinery and material at the construction site it is necessary to plan the construction process.

A rough planning without large data material is possible when using simple machinery materials for a simple structure. Then the planning resources are quite small so that the plan can be realized manually. If the construction is composed of difficult structures and if complicated machines with automatic process is to be used, a precise planning with detailed values of high accuracy is necessary. This expenditure of planning can only be carried out by computation.

A planning by means of a computer may not be restricted only to single subjects. A draft has to be developed for the realization of the complete planning with the planning of the site facilities, of the operating planning and of the material and equipment management.

This draft was performed at the University of Kassel. By means of this draft the construction management problems can be solved with the help of a computer. The operation and the conversion of this draft is shown at an example of the organizational planning of a construction site.

1. A BASIC MODEL FOR CONSTRUCTION MANAGEMENT PROBLEMS

The construction management problems are divided into four operating systems:

The procurement of orders with acquisition and calculation of offers; the order fulfillment with controlling of the construction site; the operations scheduling with the problems of site facilities and the scheduling and preparing of the production system; the re-calculation for controlling the construction project.

When working with the single operating systems it is impossible to separate them neither within temporal nor operating sequences. The network of the single operating systems is shown in fig. 1.

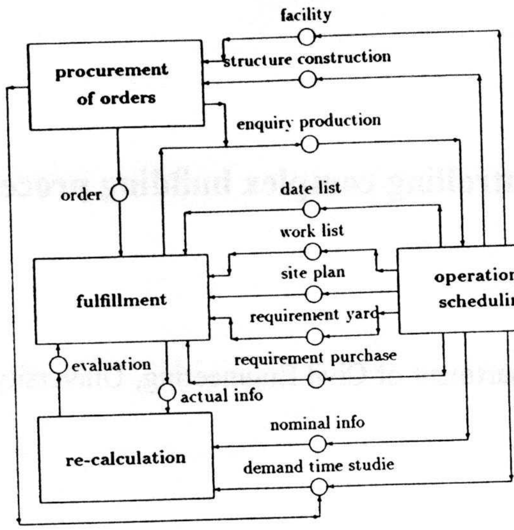

Figure 1: the network the four operating systems in the construction management as an petri-net

The petri-net-method was chosen as the basic model for the representation. By the means of the petri-nets the organizing relations of the construction management problems can be compiled. It is possible to improve the separate operation systems until obtaining the finished programme part.

In the network the operation systems are shown as events (in the shape of rectangles). The exchange of information and data between the events is shown as conditions (in the shape of circles). In fig. 1 the events and conditions are shown in a very general way, they are described more detailed within the improvements. When exchanging the information and data only the internal interfaces are shown in order to describe the relations between the separate operation systems in a better way. The external interfaces are included into the improvements of the separate operation systems.

The influence, which is exercised by the operations scheduling on the procurement of orders and on the order fulfillment, and the dependence of the control from the operations scheduling are clearly to be seen. The operation system *operations scheduling* can be called by the other operation systems at any time; and it has to be able to react very differentiately to the degree of detail of the desired results. The importance of the operations scheduling is evident.

Because of the fact that the operation systems *operations scheduling* and *re-calulation* could be quit, it is clear that the shown working organizations are in accordance with the grown structures of the German building economy, and no new working methods are installed. The conditions like the schedule, the planning of the building site equipment or the valuation of the building site are made by many companies by improvization or by estimation. Thus the operation systems *procurement of orders* and *order fulfillment* only work with limitations. The demanded aim of quality, costs and terms is only achievable in combination of all four operation systems.

It must be emphasized that the working organization has to reflect the existing working methods of the constructions companies in order to obtain a general acceptance of this model. The computer aided operation systems which are developed from this working organization have to be adapted to the working methods of man. Man should not adapt oneself to the working method of the computer. The petri-nets are an excellent instrument for combining the different working methods of man and computer.

2. THE MODEL OF OPERATIONS SCHEDULING

All tasks, which are necessary for the planning and provision of resources of the future building project, are performed in the operations scheduling (fig. 2). By the means of the operation system *choise of production method* a standard of production for the building project is made. On this basis the *site facilities* can be planned, and the *labor calculation* can be made in details. The *scheduling* finds out the period of the building project and the date of provision for workers, equipment and material. The necessary amounts of the production factors are summed up in the *determination of requirements.*

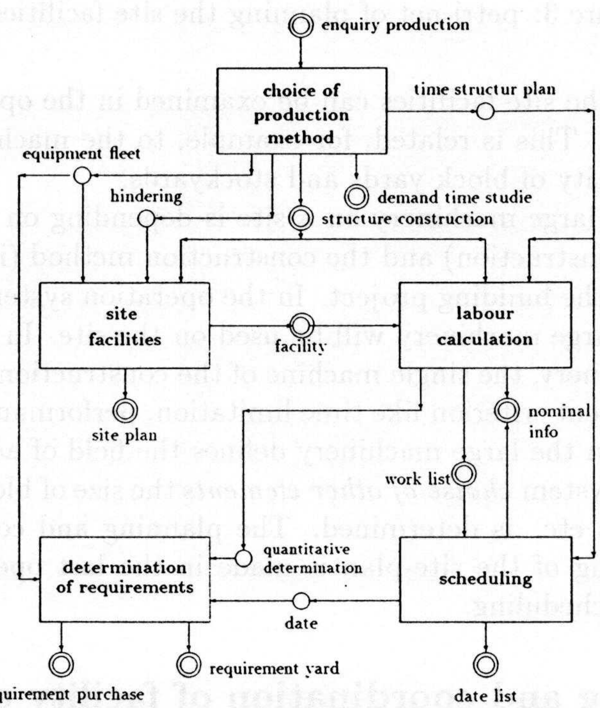

Figure 2: petri-net of operations scheduling

2.1 The planning of the site facilities

A new site has to be set up for each new building. In the building production the planning of a factory is called planning of a site facility (fig. 3).

Precondition for the planning of the site facilities is the arrangement of the construction into process stages and its rough date structure. When these two facts are known, the

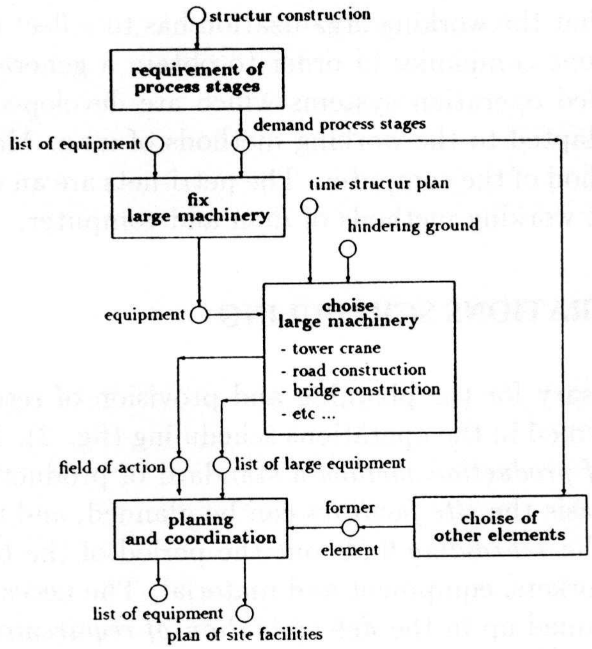

Figure 3: petri-net of planning the site facilities

single process stages at the site facilities can be examined in the operation system *requirement of process stages.* This is related, for example, to the machinery and equipment provision or to the quantity of block yards and stockyards.

The use of the proper large machinery on a site is depending on the branch (i.e. high rise building or bridge construction) and the construction method (i.e. in-situ concrete or precast construction) of the building project. In the operation system *fix large machinery* it is determined which large machinery will be used on the site. In compliance with this screening for large machinery, the single machine of the construction company is analysed and selected on requirement criterion like time limitation, performance or geometry of the building. The decision on the large machinery defines the field of actions on the site.

In the next operation system *choise of other elements* the size of block yards, stockyards, barracks for the workers etc. is determined. The planning and coordination of facility elements and the drawing of the site-plan is made in the last operation system of the petri-net of operations scheduling.

2.2 The planning and coordination of facility elements

A computer-aided system of *planing and coordination of facility elements* must optimize the cooperation between the different facilities of the site.

The process on the building site has to be shown by means of a simulation model. The single elements of the site are stored as prt-net, as macros, and they can, according to the construction site, be built into a main model which shows the whole building site. The predicates bring the single prt-nets together and they display the site facilities.

The chronological processes in a prt-net are brought about by the items. The construction elements, its assembly sequence and assembly period are presented by the items. According to this the process on the site can be simulated with a prt-net. The spatial arrangement of the facility elements can be explained by an evaluation system, and a comparison between the different arrangements is possible. The shown prt-net structures of a building site have been developed and tested by the NED-programme of the company PSI-Berlin.

3. COMPUTER AIDED OPERATION

In figure 4 you will see the prt-net for the simulation of a crane movement. This net is divided into three sub-nets *inspect crane movement*, *perform crane movement* and *perform local movement*. In the first sub-net *inspect crane movement* the actual positions of the tower and its hook will be determined. According to the target data of a construction component the movements the crane has to do will be defined. First will be checked if the crane has to move on the track system. The second sub-net *perform crane movement* simulates the crane motion on the track system and the third sub-net simulates the movements of swinging, lifting, lowering and cat-driving. In this sub-net the coordinates of the target of swinging, lifting, lowering and cat-driving will be analysed and then the movement will be simulated.

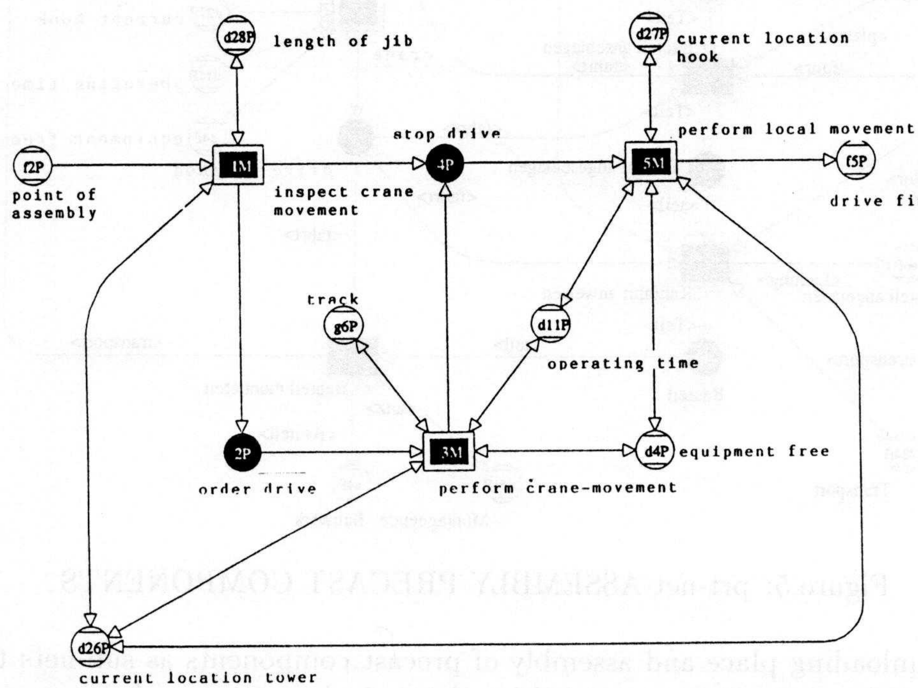

Figure 4: prt-net CRANE

To control the crane it is necessary to know the coordinates of the loading point (i.e. to chip formwork or precast components) and the exact place where the building component will be located within the construction. The prt-net for simulating the crane movement determines the settelment profile of the crane necessary for each placement of construction components. By this means it is feasable to write a report of movement, which for example can be used to control an automatic crane.

For the function of the prt-net *crane* it is requisite to indicate the point of assembly (f2P) of the construction component. The crane will move to that point and the sub-net will signal the main-net that the movement is finished (f5P). For the control of the crane data on the length of the jib (d28P), the actual location of the tower (d26P) and of the hook (d27P) are required. In order to keep a record on disturbing influences, like repair or breakdown of the crane, the current operating time (d11P) is of interest. After the information *equipment free* (d4P) the crane is ready for renewed employment.

The further account on the simulation of a site refers to the process of assembling precast components. The prt-net *crane* will be installed in the prt-net *assembly precast components*. This prt- net (figure 5) comprises the chip of construction components, the control of the crane and the assembly of precast components. The prt-net *assembly precast componemts* itself is a sub-net of the prt-net *building site* which is shown in Figure 6.

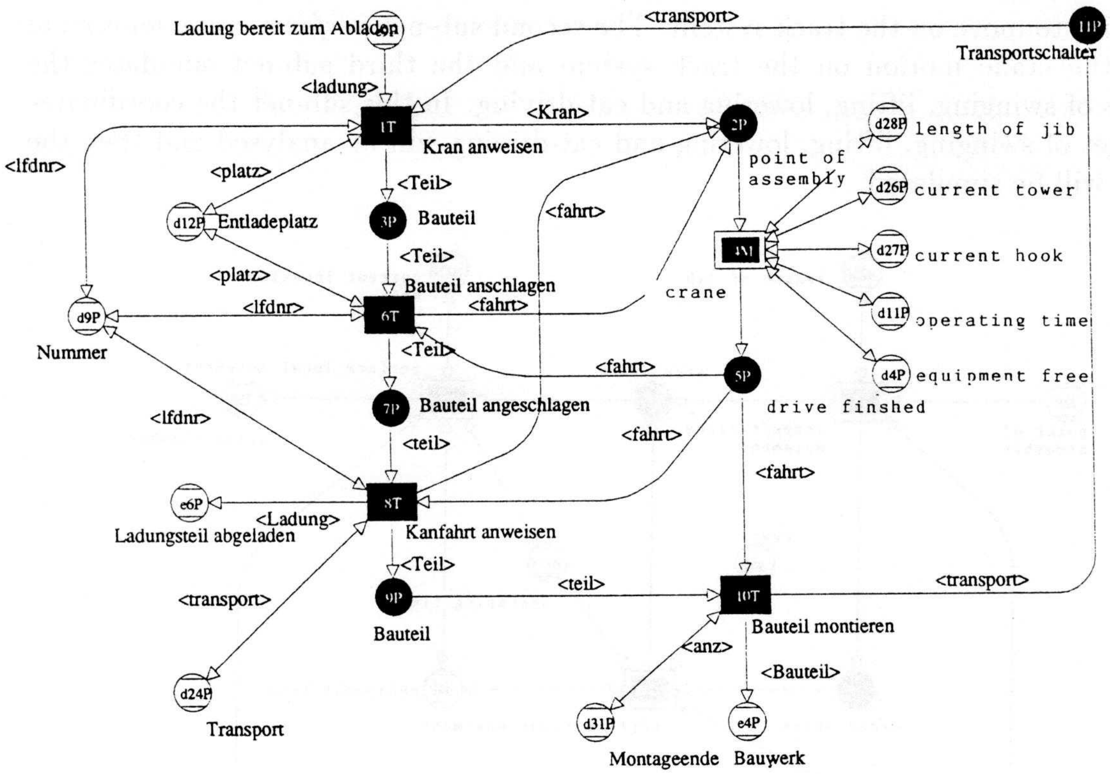

Figure 5: prt-net ASSEMBLY PRECAST COMPONENTS

With the unloading place and assembly of precast components as sub-nets the central processing on the site will be extended by the arrival, waiting and departure times of the lorries. This prt- net (figure 6) represents the site. The prt-net *building site* can be extended by other sub-nets like stockyards, factory yards, barracks for the workers or special production processes (e.g. framework or feed scaffold etc.).

The prt-net macros are developed in a way that the predicates (shown as circles) are definite interfaces. In case of a further development it will be feasable to hide a prt-net graphically behind a picture and the user can draw the site by means of symbols. The

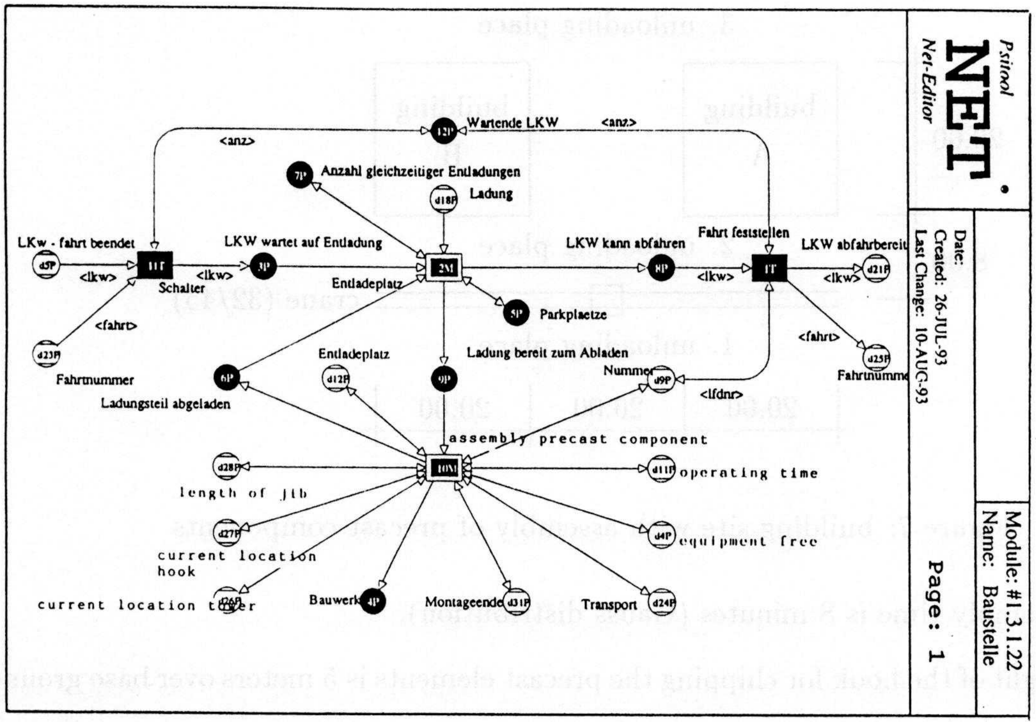

Figure 6: prt-net BUILDING SITE

connection of the interfaces are clearly determined by the predicates.

It is the aim of the computer-aided system *planning and coordination of facility elements* to place auxiliary means at the user's disposal when outlining a site. The whole system is compiled in a way to allow the user to establish a design of a building site. The program simulates the chosen site. A self- reliant coordination by the program is not allowed. The program is intended to support the user, not to replace him.

3.1 Example assembly: precast components

An example for the application of the prt-net *building site* described above (figure 6) is given by a building site for the assembly of precast components. The building consists of two towers to be erected on an already existing platform. For each tower 25 precast elements have to be installed. Delivery and assembly are controlled by the prt-net.

The clerk of works responsible for this site must find the most suitable places for the crane and the unloading of the precast elements. Furthermore he has to determine the kind of crane required. For the choice of location three versions are investigated: The unloading place is situated between crane and building (1), the crane is placed between the unloading place and the building (2) or the unloading place is situated behind the building (3). For the choice of the kind of crane there are two posibilies: The first one is to use a roadway tower-crane with a jib of 32 meter length, the second one is to use a stationary tower-crane with a jib of 45 meter.

The simulation is based on the following assemptions:

- the time for chipping each precast element is 1.5 minutes (Gauss distribution), and

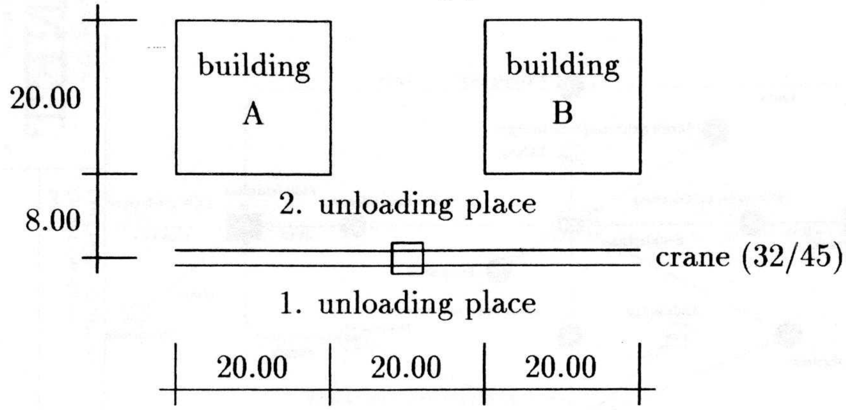

Figure 7: building site with assembly of precast components

the assembly time is 8 minutes (Gauss distribution).

- the height of the hook for chipping the precast elements is 5 meters over base ground.
- the driving time of the lorries is 30 minutes (Gauss distribution). They will be loaded with between 4 and 12 precast elements (equal distribution). The precast elements will be mounted in the order of arrival.

CONCLUSION

Depending on the user's requirements the evaluation of the site facilities can be taken from the different predicates. In our example solely the maximum construction time was observed. Each of the six alternatives have been simulated three times, and the result of the construction time is shown in table 1.

	jib 32 Meter	jib 45 Meter
1.place	13:15 h	12:40 h
2.place	12:39 h	12:39 h
3.place	16:20 h	12:36 h

Table 1: construction time by simulating six alternatives of building sites

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