Network Planning Method in Optimizing Vessel Utilization – Laytime Calculation

Primjena metode mrežnog planiranja u funkciji optimizacije iskorištavanja broda – određivanje vremena iskrcaja broda u luci

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DOI 10.17818/NM/2018/3.3
UDK 656.02
Preliminary communication / *Prethodno priopćenje*
Paper accepted / *Rukopis primljen:* 9. 1. 2018.

Summary

The network planning method was chosen as a possible solution to management of optimizing vessel utilization. In addition to graphical presentation and project monitoring, this method allowed obtaining sufficient quantity of relevant information necessary to manage its realization. It was illustrated with a hypothetical example of applying the network planning method in optimization of transhipment of containers in terms of time only, although the full contribution of network planning would be possible in the case of optimization of multimodal containership transport.

KEY WORDS
container transport
network planning method
multimodal transport

Sažetak

Kao moguće rješenje optimizacije upravljanja iskorištavanjem broda izabrana je metoda mrežnog planiranja. Ta metoda omogućava, pored grafičkog predstavljanja i praćenja projekta, pribavljanje dovoljnog broja potrebnih informacija koje su neophodne za upravljanje njegovim ostvarenjem. Ilustrirana je hipotetskim primjerom primjene metode mrežnog planiranja u optimizaciji isključivo vremena pretovara kontejnera u luci, iako je pun doprinos mrežnog planiranja moguć u slučaju optimizacije multimodalnog transporta kontejnerskog broda.

KLJUČNE RIJEČI
kontejnerski transport
metoda mrežnog planiranja
multimodalni transport

In order to illustrate the possible solutions to management of optimizing vessel utilization, we chose the method of network planning[1] among many other methods. The use of network planning in vessel management and exploitation is applicable since it allows, in addition to graphical presentation and project monitoring, obtaining sufficient quantity of relevant information that is necessary for management of its implementation. Illustration was based on a hypothetical example of applying the network planning method in optimization of transhipment of containers in terms of time only, although the full contribution of network planning would be possible in the case of optimization of multimodal containership transport.

The research problem has determined the working hypothesis: Determining all the relevant features of the container transport costs (during the segment of voyage, i.e. navigation, or when a vessel is at berth, as well as additional costs occurring in both segments of voyage), and defining and evaluating the elements of costs of these transport system will affect the overall development of multimodal transport system, which is directly related to the faster inclusion of Croatia into the European integration process.

The need to increase productivity in the container transhipment process is in direct correlation with one of the basic criteria for optimizing management of port services, which can be rationalized with as short vessel laytime as possible. The tendency of increase in the amount of cargo transported by containers requires detailed study of container transport system by sea in order to achieve optimum functioning of the observed system. Network Planning Technique (NPT) is a common name for a number of procedures in project planning and management, whose common feature is a graphical model of process flow, a so-called network diagram. Figure 1 presents the concept of network planning model.

Detailed process elaboration is seen in defining and presentation of process elements, structure and operating rules. By describing these values an abstract image of the process, i.e. its model, is created. A model does not present all details of reality, and this feature of the model allows separation and emphasizing the most important ones from the infinite number of facts. This allows for transparency and easy to understand the

[1] Network planning methods were created as a result of substantial time and cost deviations compared to defined goals. It was introduced in the middle of the 20th century, and today not a single complex project can be realized without this method. The first network planning method was Critical Path Method (CPM), and it was followed by Program Evaluation and Review Technique (PERT).

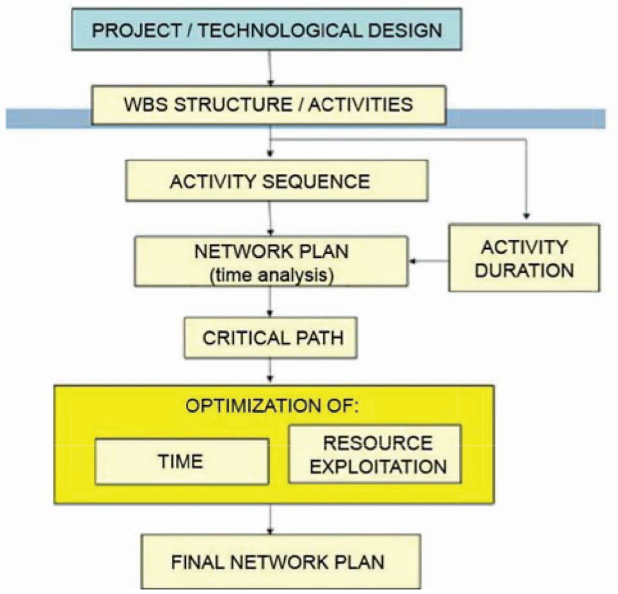

Figure 1 Concept of network planning

Slika 1. Koncept mrežnog planiranja

basic relationships in the process.

The purpose of process modelling is to provide the necessary information for its management and regulation.

In network diagrams processes are shown through graphs where arrows represent process activities, while nodes represent process events. Network diagrams depict the dependencies between activities and their order, which then serves to predict the duration of each activity, engagement of needed resources regarding their type and scope, as well as anticipation of costs.

The essence of this method is the ability to separate structure analysis and time analysis. By structure analysis we mean establishing a logical sequence and interdependencies of certain activities to be carried out within a particular project or work. The term "Network" here refers to the sequential organization of tasks within a project. It shows the interdependencies of certain activities and sequence of their performance. It also allows monitoring of parallel activities in the project.

There are basically two methods of network diagrams, CPM and PERT, and as network planning methods they are largely similar. Both methods use graphical presentation of the project which represents project network. CPM is a project analysis technique used to predict total project duration. Critical path of the project is the series of activities that determine the earliest completion time of the project. The critical path is the longest path through the network diagram and has the least amount of slack or float.

CPM method is used in cases where the duration of each activity in the project is known and can be determined and added in calculation. Based on duration of each activity, the time needed to complete the overall project is calculated.

PERT method is applied when individual activity duration is unknown and cannot be clearly determined. In this case, duration of each individual activity is estimated as: optimistic time, pessimistic time and most likely time, which serves to calculate duration of all activities in the project.

PERT is a project network analysis technique used to estimate project duration when there is a high degree of uncertainty with individual activities during estimation.

PERT uses probabilistic duration estimates, using optimistic, most likely, and pessimistic estimates of activity durations.

A finish-to-start relationship – a dependency relationship where the first task must be completed before the second task can start. Delay of predecessor task will most likely cause delay of successor task, as well as all the tasks that follow, thus endangering the completion of the project within the given deadline.

In network diagrams with determined activity duration, the duration of the path is determined with the sum of all activities involved. Critical paths are completed paths with the longest duration. They determine the duration of the whole project. The tasks that form the critical path are known as critical tasks, and events as critical events. Critical path and activities that it consists of must be monitored with special attention, so for this reason the time analysis is named the critical path method[2]. Full paths in the network diagram do not have to have the same duration. The difference between full paths with longest duration and duration of a complete path is known as reserve time of the observed path. Reserve time indicates the amount of increased duration of a full path without delaying the total duration of the project. Duration of paths in the network is just one part of time analysis in the network diagram. The network planning technique allows transformation of the monitoring system into the management system. The project completion time is particularly significant today because problems need to be solved quickly. This means that setting deadlines for individual tasks and the project as a whole is very important.

The time analysis includes calculating the duration of the activities represented in the network diagram. By setting time parameters we can control the timing of the project, keep within the deadlines, as well as control and manage the project. Determining the precise duration of an activity is conditioned by an accurate description of procedures for its execution. Time analysis is performed independently of the structure analysis. Two very similar methods are used in time analysis or for calculating duration of a single activity: PERT (Program Evaluation and Review Technique) and CPM (Critical Path Method). For the activity between events (i-j), its duration t_{i-j} is determined. The time t_{i-j} is expressed in time units and is noted under each activity in the network diagram.

Event formation time is recorded according to Figure 2.

Network activities are merged into the path from the starting to the ending event of the network. The most important path of all paths in the network is the one that takes the most time units (longest or critical) because it denotes the duration of the entire project.

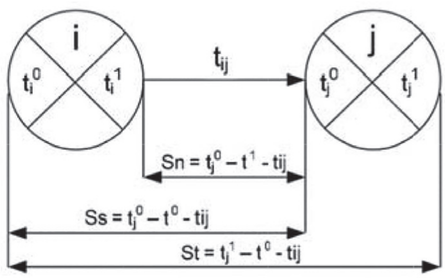

Figure 2 Event durations

Slika 2. Trajanje događaja

[2] J. Petrić, *Operaciona istraživanja*, Naučna knjiga, Beograd 1987.

Activity (i-j) can start only after the event 'i' has taken place. If there are more than one activity preceding the event 'i', it can take place only after the longest activity has finished.

T_{Ei}- Early Start of an activity (i-j);

T_{Ej}- Early Finish of an activity (i-j)

$T_{Ej}= T_{Ei}+tij$ (max)

T_{Lj}- Late Start of an activity (i-j);

T_{Lj}- Late Finish of an activity (i-j)

$T_{Li}= T_{Lj}-tij$ (min),

Namely, it starts from the final event of the project and goes toward the initial event.

$(T_L)_j – (T_E)_i$ → maximum allowed duration of an activity (i-j).

Critical path is a path starting from the initial event 0 to the event "N" and has the longest duration. In other words, it is a path containing only critical activities (time reserve equal to 0). Duration of a critical path determines the duration of the entire project.

In addition to a critical path, there are also subcritical paths, which are paths with a very short time reserve.

Here follows the determination of time with PERT method, which is applied in the paper.

Time analysis by PERT method is carried out through the following stages:

- Time estimation (a,m,b),
- Calculation of expected time and variance,
- Determining the earliest and latest starting time of events,
- Determining critical and subcritical paths
- Determining the probability of an event

Time estimation

Since project activities have stochastic character and their duration cannot be standardized, three different time values are estimated for each activity:

1. Optimistic time – a_{ij}, (minimum time)
2. Most likely time – m_{ij}, (time needed) $a_{ij}>m_{ij}>b_{ij}$
3. Pessimistic time - b_{ij}, (maximum time)

Time estimation is performed by the experts who have experience in doing similar activities, or who will be entrusted with performing the given activities.

Calculation of expected time $(t_e)_{ij}$ and variance $(\sigma^2)_{ij}$

It is necessary to determine the most probable completion time for each activity in order to perform it. In PERT method, this time is called the expected time and represents the mean time taken to perform an activity during its multiple recurrences.

$(t_e)_{ij} = (a_{ij}+4_{mij} +b_{ij})/6$ - expected time of an activity

$(\sigma^2)_{ij} = (b_{ij} – a_{ij})^2/6$ - variance

Variance is a measure of uncertainty in estimating the time for performance of an activity. In order to manage the implementation of the project, it is necessary to determine the critical path.

In order to do this, it is necessary to previously specify the time reserve S, which is the time difference between the latest completion of all the preceding activities, and the earliest start of the activities that immediately follow.

$(Si) = (T_L)_j – (T_E)_i$; i,j = (1,2,3...n)

S_i – there is time reserve, capacity and other resources

S_i – there is no reserve (critical path)

S_i – project cannot be realized without intensification of activities

Faster data processing in information system due to increased hardware characteristics and application of modern software solutions (software solutions for various stages of processes in seafaring) was enabled by a large number of ready-made software programs. It is particularly related to project management system, i.e. EPM (*Enterprise Project Management*), which is applied in network diagram techniques[3].

The following example will show the application of a network diagramming technique in optimizing transhipment time at the port terminal. During half a century of container transportation, the volume of traffic has increased significantly and new container handling equipment for terminals has been developed.

With the help of port mechanization, nine basic handling operations can be performed at port terminals in the following relations: ship – port and vice versa, port – storage area and vice versa, and storage area - hinterland transportation and vice versa. In these operations, there are two basic technologies for handling containers which can be combined:

- Lo-Lo (Lift on - Lift off) transhipment system using cranes,
- Ro-Ro (Roll on - Roll off) transhipment system using special towing vehicles.

The time needed for loading / unloading depends on the number of containers that must be moved from the ship to the shore and vice versa, on the net productivity of a gantry crane, on the number of gantry cranes that will serve the ship and on the coefficient of their interference. The structure of the ship's time in a port consists of: the time of approaching the berth, the time at berth, container unloading time, singling up time, departure time, and possible simultaneous ship supply or minor repairs while loading / unloading. The time needed for gantry cranes to prepare for loading / unloading should also be taken into account, but this operation is assumed to be performed while the mooring operations take place.

A port container terminal is a stochastic system in which ship arrivals and duration of port services are random variables in the statistical sense. In addition, a port system is composed of several subsystems, all of which act both as separate entities and as elements of the entire system, so that output values of a subsystem represent input values of the next subsystem[4].

From the example of time calculation, a vessel laytime in port C will be illustrated. With the analysis of transhipment effect on the time containers spend at the terminal, functional interdependencies between observed variables were established, and based on that their list was given in Table 1. Based on the activity structure given in Table 1, the time calculation is performed, a network diagram with interdependences of port activities is shown, and a critical path is defined. By optimizing the duration of activities in port C, it is possible to save time.

Based on the flowchart with technological process of loading / unloading of containers, we should establish a logical sequence (connections) of activities:

- Determine which activities must be completed before the observed activity starts
- Determine which activities can take place alongside the observed activity

[3] Microsoft Project is one of Microsoft Office software programs and due to its popularity is already much more acceptable and accessible than other competitors' programs. http://office.microsoft.com/en-gb/project/default.aspx

[4] Z. Zenzerović, „Kvantitativne metode u funkciji optimalnog funkcioniranja sustava kontejnerskoga prijevoza morem", Pomorski zbornik, Vol. 43, No. 1, 2005., pp. 165-191.

Table 1 Port activities
Tablica 1. Aktivnosti u luci

Activity mark	Activity	Optimistic time T_r (minute)	Pessimistic time T_k (minute)	Most likely time T_{sr} (minute)
a	Sailing from the pilot station to the mooring station	20	30	25
b	Tugging and mooring	20	40	30
c	Customs and port formalities upon arrival	15	25	20
d	Positioning of a gantry crane	15	25	20
e	Manipulation – loading / unloading	240	320	280
f	Ship supply	240	320	280
g	Customs and port formalities	15	25	20
h	Tugging – departure manoeuvre	15	25	20
i	Sailing from the berth to the pilot station	20	30	25

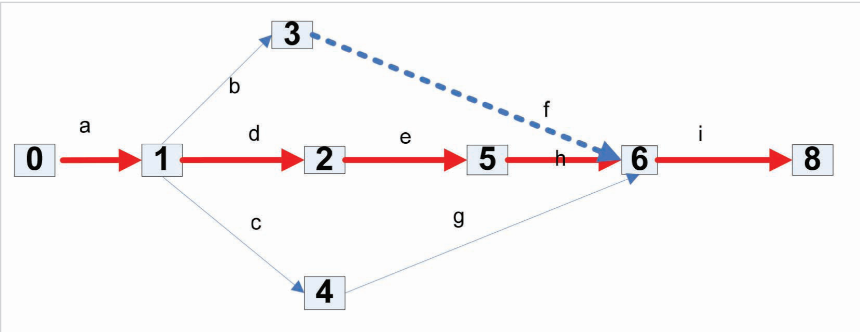

Figure 3 Network Diagram of activities at the port terminal
Slika 3. Mrežni dijagram aktivnosti u lučkom terminalu

- Determine which activities can start immediately after the observed activity
- Check whether a particular activity can be divided into multiple individual activities for parallelization

The time analysis is performed according to the following equations:

$(t_e)_{ij} = (a_{ij}+4_{mij} +b_{ij})/6$ - expected time of activity

$(\sigma^2)_{ij} = (b_{ij} - a_{ij})^2/6$ - variance

$(t_a)_{ij}$ =(20+4x25+30)/6=25min (σ^2)=(30-20)²/6=16.6

$(t_b)_{ij}$=(20+4x30+40)/6=30min (σ^2)=(40-20)²/6=66.6

$(t_c)_{ij}$=(15+4x20+25)/6=20min (σ^2)=(25-15)²/6=16.6

$(t_d)_{ij}$=(15+4x20+25)/6=20min (σ^2)=(25-15)²/6=16.6

$(t_e)_{ij}$=(240+4x280+320)/6=280min (σ^2)=(320-280)²/6=266.6

$(t_f)_{ij}$=(240+4x280+320)/6=280min (σ^2)=(320-280)²/6=266.6

(tg)ij=(15+4x20+25)/6=20min (σ^2)=(40-20)²/6=66.6

$(t_h)_{ij}$=(15+4x20+25)/6=20min (σ^2)=(40-20)²/6=66.6

$(t_i)_{ij}$==(20+4x25+30)/6=25min (σ^2)=(30-20)²/6=16.6

The activities on the critical path are $(T_{kr})_{min}$ = a+d+e+h+i= 20+15+240+15+20=310.

The optimistic version says that the laytime of a ship in port may be 310 min.

Activities on the critical path are $(T_{kr})_{max}$= a+d+e+h+i =30+25+320+25+30=430.

According to the pessimistic version, the laytime of a ship in port may be 430 min.

CONCLUSION / *Zaključak*

Contemporary relations of supply and demand for ship space, as well as changes in these relations in liner shipping, directly and indirectly affect the costs and freight rate.

The main tasks of port and shipping services in multimodal networks are: increase and acceleration of cargo flow in ports, better and faster supply of ships in ports, reduced time in ports, rationalization of port operations (in space, time, and communication), rationalization in co-operation with land transport, quality communication with port hinterland, optimization of information support, quality communication among the operators of the port system, minimization of idle time, slowdown and the like, as well as improving the quality of port logistics system (means of transport, information and control systems, personnel, coordination processes etc.).

Container liner shipping, in terms of contemporary liner shipping, is characterized by only one type of cargo - containerized cargo. The advantages of transporting cargo in containers, in relation to the conventional methods and in terms of costs are reflected primarily in shortening laytime duration, i.e. reducing overall vessel travel costs. It is particularly important to emphasize the impact on reduced time between the manufacturer and the recipient of goods, i.e. the end consumer, as well as improvement in transhipment within multimodal transport, and uninterrupted transhipment operations under all weather conditions, all with fewer groups of workers needed for loading operations in transhipment process, and significantly shorter time required to clean the ship after unloading.

In container liner shipping there are fully equipped modern container ships, which have some specific utilization features such as mother ships, unlike feeder ships which operate on shorter routes, and can provide the entire transport capacity. The specificity is in ship's capacity which operates with only on one type of cargo (containerized cargo) and is most often related to multiple shippers, which significantly affects the structure and cost allocation. Such a container ship (especially the mother ship) has a steady route and connects multiple ports of loading and ports of discharge, while a feeder ship also has a steady route connecting smaller number of ports of loading and ports of discharge.

It can also be concluded that the technological efficiency of a container ship depends directly on modern technical and technological features of a container ship (mother ship and feeder ship) and other transport means participating in the containerization, and also on transport infrastructure and superstructure of container terminals that the ship is in contact with in the course of its line travel. Also, quality information system on board, compatible and complementary to information systems of other participants in containerization (freight forwarders, shippers, consignees ...) is a prerequisite for realization of technological efficiency of a container ship's journey. In order to achieve technological efficiency of a container ship's journey and optimum utilization of the ship, besides modern technical and technological container ship features, it is necessary to integrate the land and maritime components of containerization from the aspect of multimodal transport and adequate cost management. Container ship today can be seen as a logistics system that provides the full transport service, and not only a liner shipping carrier, because its transport activity directly and indirectly spreads and connects both the sea and the land.

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