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MODELLING OF THE SHIP LOCKING PROCESS IN THE ZONE OF SHIP LOCK WITH TWO PARALLEL CHAMBERS

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ABSTRACT: Being aware of the waterway capacity, as a substantial characteristic of each traffic way, has a great importance to authorities that perform control and regulation of the vessel traffic. In specific real conditions and situations, for the purpose of the vessel traffic control, it is necessary to know specified limits of traffic density, which depends on corresponding parameters of observed system (ship lock zone). The vessel traffic control in the zone of ship lock is a complex system that is made of numerous subsystems. Determination of subsystems and their external and internal connections is conducted according to analysis of a real system. Simulation model is developed according to the analyzed model of vessel traffic process. Developed simulation model contain data on vessels which have passed through the observed system in defined time interval. Also, it contains statistic data on number of vessels and delays due to waiting queues for locking. An application of this model is possible in all cases of the waterway capacity determination by varying numerical data. Obtained results may be used as a planning and decision-making support in the process of the vessel traffic control in the zone of ship lock with two parallel chambers.
KEYWORDS: ship lock, navigation, simulation, model

INTRODUCTION

Capacity is one of the most important characteristics of transportation systems. In analysis of traffic flows, the capacity should be distinguished from the traffic density. Capacity of the waterway is the maximal amount of cargo per time unit (day, month, and navigation period) for specific technical characteristics of waterway and fleet, as well as appropriated type of traffic organization. The waterway capacity can be measured according to two parameters: the amount of cargo per time unit (as a basic parameter) and the number of vessels per time unit (which is often applied in a real system).

The growth of traffic density on waterways initiated research of capacity determination and how to increase it. Each traffic system is complex system. Capacity determination of such system requires complex analysis of present state and existing problems, as well as possibilities to solve them. Magnitude of the waterway capacity, as a substantial characteristic of each traffic way, has a great importance for institutions and services that perform control and regulation of vessel traffic. Analytical methods for waterway capacity determination give average values of capacity [5]. In specific real situations, besides the vessel traffic safety [6], activities in vessel traffic control and decision-making processes require knowledge of traffic density limits, which depend on parameters of observed system.

Being aware of the capacity of certain waterway requires preliminary determination of influential factors and their effect on capacity quantity. Technological process of navigation is defined according to connections between elements and changes of the system state during navigation. After that follows model development and realization of simulation experiments. The capacity of the most difficult section of observed waterway determines capacity of the waterway as a whole. It is possible to establish upper limit (maximal value) of waterway capacity as a whole by comparison of particular waterway section capacities, i.e. “bottle necks” based on capacity. When the traffic density on observed waterway reaches the limit values under certain technical and exploitation conditions, it is necessary to determine the waterway capacity for changed mode of exploitation (i.e. for changed technical characteristics and/or mode of exploitation). Some authors [9], [7] most attention give to determination of the ship lock capacity and its impact on the vessel traffic.

While studying problem of waterway capacity it is necessary to set apart natural and artificial sections of waterways. Natural waterways and canals can be divided into sectors: navigable sections and those that include objects on waterway (ship locks, inclined plane, boat lifts or other).

ORGANIZATION OF TRAFFIC AND TECHNOLOGICAL PROCESS OF NAVIGATION

The traffic organization on the waterway is represented by set of rules and activities for the control of navigation in the waterway, in order to perform rational utilization of waterway capacity and reduce time delays of vessels, with respect to existing navigational rules and the safety level of navigation. The traffic organization on the waterway or the section of waterway depends on [1]:

- technical and exploitation characteristics of the waterway and objects on the waterway
- technical and exploitation characteristics of fleet
- traffic density
- number of different types of vessels in fleet
- priority of specific vessels
- hydrological and meteorological conditions.

Each organization scheme is characterized by certain technological process of navigation (ship passing process or ship locking process). Also, for a certain type (scheme) of the vessel traffic organization there are different technological processes of navigation depending on vessel characteristics.

Technological process of navigation is presented by set of activities with defined phase change schedule. The phases are influenced by specific factors and limited by duration of time necessary to accomplish certain activity. Technological process of navigation depends on:

- an appropriate traffic organization scheme
- traffic density
- priority of vessels
- navigation conditions on the waterway
- technical and exploitation characteristics of objects on the waterway
- technical and exploitation characteristics of fleet
- hydrological and meteorological conditions.

There are following groups of technological processes depending on exploitation conditions on waterways' sections:

- technological process of navigation in two-way navigation sections
- technological process of navigation in one-way navigation sections
- technological process of navigation in zones of ship locks.

ORGANIZATION OF TRAFFIC IN THE ZONE OF SHIP LOCK

Organization of traffic on the waterway in the zone of ship lock, i.e. organization of ship locking process, is a compromise between the rational utilization of ship lock and reduction of vessels' delays in the zone of ship lock.

Organization of the vessel traffic on the waterway in the zone of ship lock depends on:

- number of locks (one or two parallel)
- number of lock chambers (one, two or more chambers in a row)
- way of ship locking process (one direction or both directions)
- technical characteristics of locks and approach canals
- traffic density
- technical characteristics of a fleet
- number of different types of vessels in a fleet
- priority level for certain vessels
- hydrological and meteorological conditions.

The factors listed above indicate a variety of organization ways, i.e. ability to determine a large number of traffic organization schemes, which depend on the degree of importance assigned to particular criterion.

From the standpoint of traffic organization and traffic density, there are three different types of navigation: free, restricted and regulated navigation [1]. The highest level is automated navigation (automated guidance). The navigation in two-way section corresponds to type of free navigation, since only restrictions in navigation are maximal allowed speed and distance between two vessels from the same direction. In other hand, navigation in a ship lock zone corresponds to type of regulated navigation.

During the ship locking process vessel changes position in real space and ship lock goes through certain phases, or states. Traffic organization scheme in a ship lock zone is influenced by adopted organization type. The technological process of the ship locking is analysed as a complex process in order to more clearly noticed specificity and mutual dependence between the state change of locks and movement of vessels. Long waiting of vessels at the entrance and vessels amassing must not be permitted.

❖ THE TECHNOLOGICAL PROCESS IN THE ZONE OF SHIP LOCK

The technological process of ship locking is divided into two main subsets:

- from the aspect of ship lock
- from the aspect of vessels.

Phases, which ship lock and vessel go through during locking process, are defined by operations which must be executed. Duration of operations depends on several factors: the state of technical equipment, hydrologic and weather conditions, number and type of locked vessels, the intensity of the flow of requests for ship locking (traffic density) and other.

The technological process of ship locking was analyzed as a complex system. It consists of different phases through which pass: only vessels, only ship lock and phases for both - vessels and ship lock. Also, there are certain activities of the control of the ship locking process. Phases are represented by following activity flows:

- flow of vessel activities (ships and compositions),
- flow of ship lock activities (with or without vessels in the lock chamber),
- flow of control activities during the ship locking process.

Technological processes of ship locking can be classified according to:

- type and technical - exploitation characteristics of ship lock, approach canals and lock pools
- technical -exploitation characteristics of vessels
- organization mode of ship locking process.

From the standpoint of the ship locking process, according to the technical-exploitation characteristics, there are following systems:

- one lock (with one, two or more lock chambers in a row)
- two parallel locks (with one, two or more lock chambers in a row).

Technological processes of ship locking can be distinguished from the aspect of locking mode: one lock - one direction and one lock - both directions.

Depending on the technical-exploitation characteristics of the fleet and the locks, or possible number of vessels in the lock chamber during one cycle, there are following relationships between the lock and technological processes of ship locking:

- one lock chamber - one vessel (relevant)
- one lock chamber - one composition (relevant)
- one lock chamber - many vessels and compositions.

Taking into account assigned priority technological processes can be classified as:

- all vessels and compositions have equal priority, i.e. ship locking process without priority
- different priority levels for certain ships and compositions, i.e. ship locking process with priorities.

Depending on the classification criterions above there are a lot of ship locks systems with the appropriate technological processes of ship locking (Table 1).

Table 1. Criterions for the classification of technological processes of ship locking

Type of the technological process of ship locking	Number of ship lock rows (1 or 2)	Number of lock chambers in a row (1, 2, …, *n*)	Number of vessels in a lock chamber (1, 2, …, *m*)	Ship lock is assigned to one or to both directions (one=1, both=2)	Number of ship priority levels (1, 2, …, *p*)
11121	1	1	1	2	1
11122	1	1	1	2	2
…	…	…	…	…	…
22*m*21	**2**	**2**	***m***	**2**	**1**
…	…	…	…	…	…
2*nm*2*p*	2	*n*	*m*	2	*p*

❖ TECHNOLOGICAL PROCESS OF THE SHIP LOCKING IN THE ZONE OF SHIP LOCK SYSTEM WITH TWO PARALLEL LOCKS FOR BOTH DIRECTIONS

Technological process of the system with two parallel locks with two chambers in a row for more vessels in one cycle will be presented in the following schemes. Both locks are designed for both directions, giving greater importance to reduction of vessels delays in the ship lock zone (type 22*m*21, part marked in Table 1).

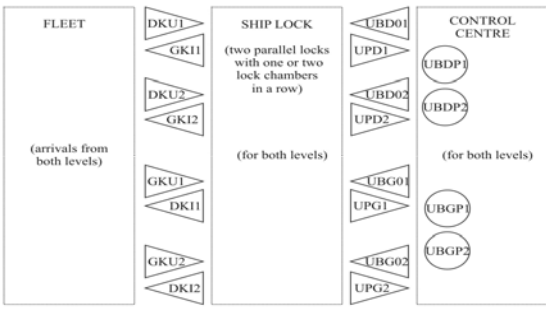

Figure 1. Connections between segments of the technological process in the ship lock zone

In Figure 1 are presented connections between segments of the technological process of navigation in the zone of a system. In Figure 2 are presented activities of vessels at both levels (arrivals from the lower and upper level). In Figure 3 are presented some lock activities at ship locking process. In the Figures 4 and 5 are presented some activities of the ship lock control centre.

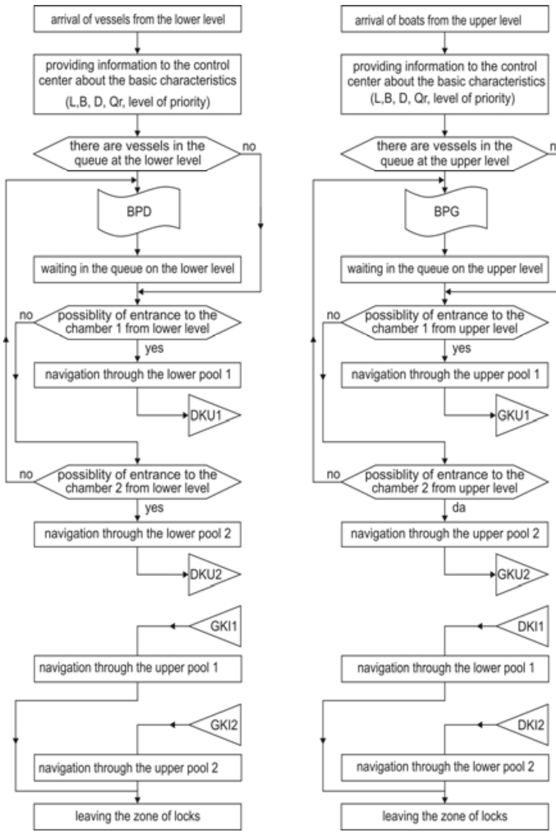

Figure 2. Activities of vessels at both levels

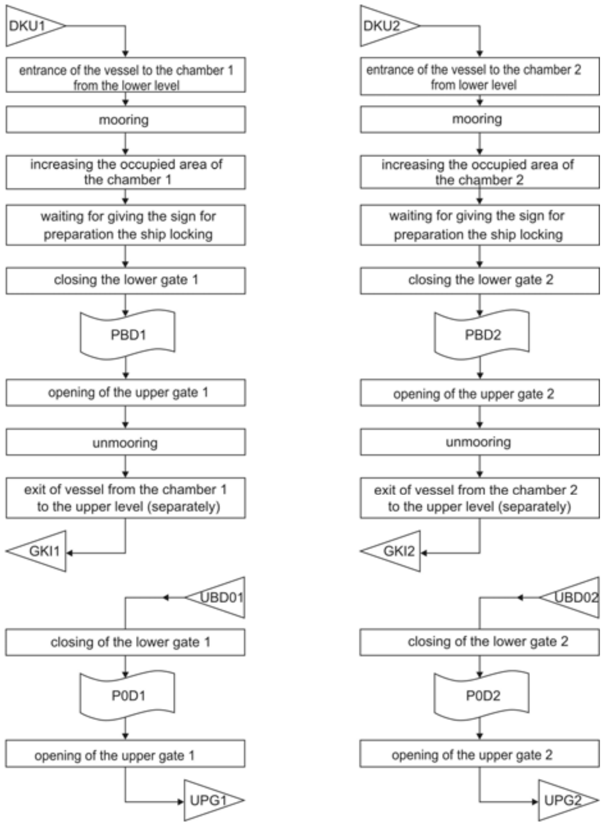

Figure 3. Ship lock activities at ship locking process (from lower to upper level)

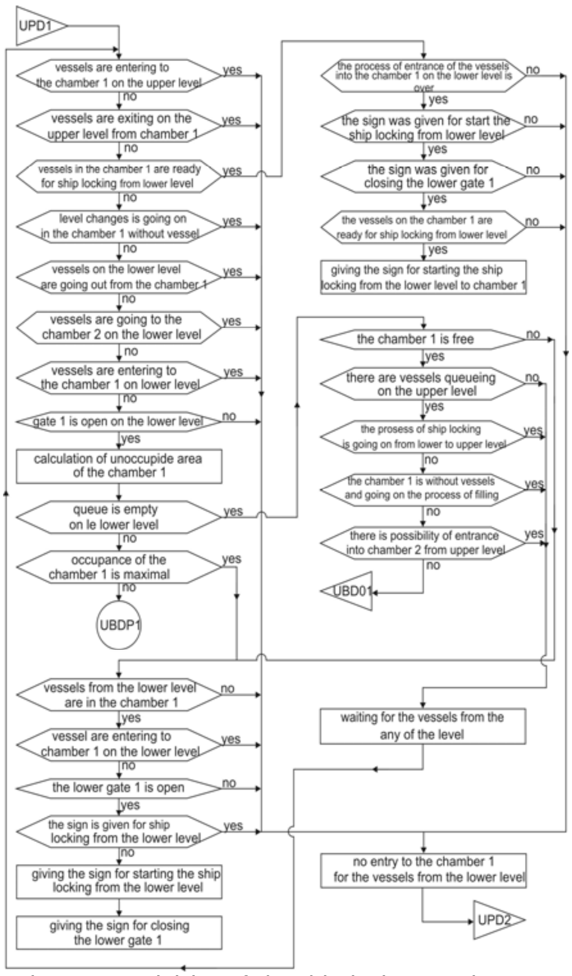

Figure 4. Activities of the ship lock control centre (locking from lower to upper level – lock1)

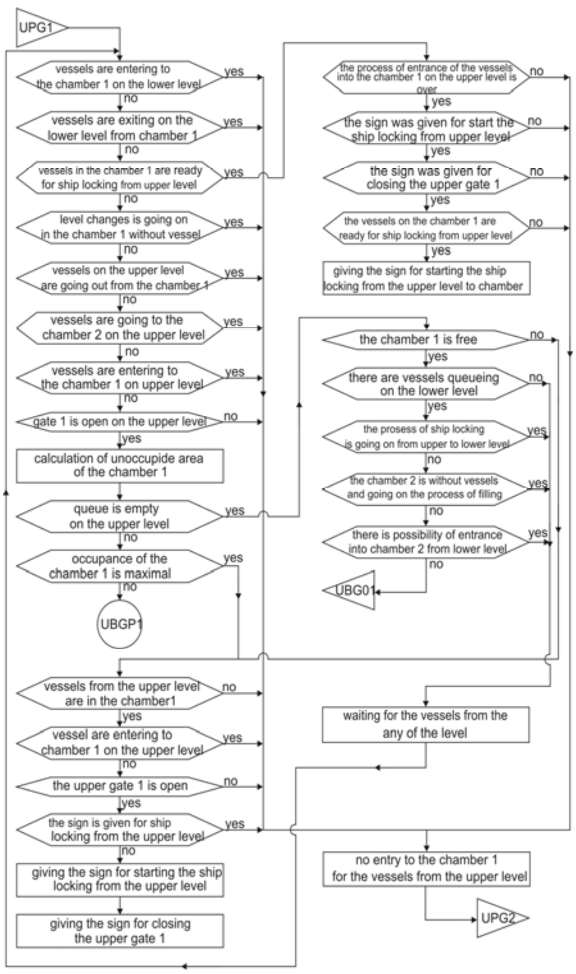

Figure 5. Activities of the ship lock control centre (locking from upper to lower level – lock1)

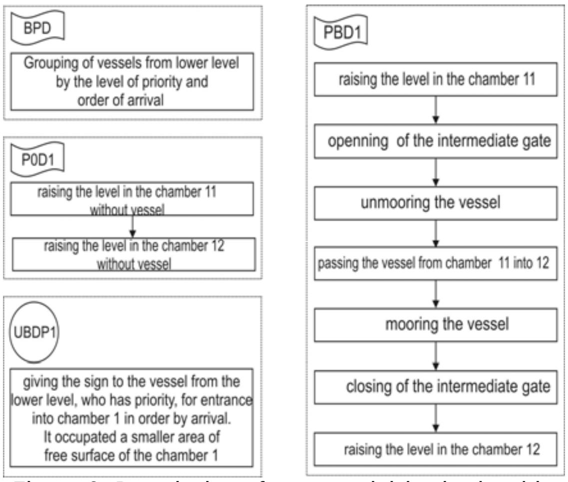

Figure 6. Description of some activities in the ship lock process

❖ SIMULATION MODEL. DESCRIPTION OF THE SIMULATION MODEL

The developed simulation model is composed of nine sub-models:

- ❖ sub-model 1 - the ship locking process for vessels from the lower level
- ❖ sub-model 2 - the ship locking process for vessels from the upper level
- ❖ sub-model 3 - the control process of the ship lock 1 during locking from the lower level
- ❖ sub-model 4 - the control process of the ship lock 2 during locking from the lower level
- ❖ sub-model 5 - the control process of the ship lock 1 during locking from the upper level
- ❖ sub-model 6 - the control process of the ship lock 2 during locking from the upper level
- ❖ sub-model 7 – the control process of grouping of vessels in the queue at the lower level, depending on: the priority level, the order of arrival and area size ($L \times B$) that occupy the vessel in the lock chamber
- ❖ sub-model 8 - the control process of grouping of vessels in the queue at the upper level, depending on: the priority level, the order of arrival and area size ($L \times B$) that occupy the vessel in the lock chamber
- ❖ sub-model 9 - time sub-model (timer).

Ship locks are static elements in sub-models 1, 2, 3 and 4, while vessels are dynamic elements in sub-models 1 and 2. Control actions are dynamic elements in sub-models 3, 4, 5 and 6. In sub-models 7 and 8, control actions are dynamic elements, while queues (if were formed) are static elements.

Sub-model 1 is the locking process of vessels from the lower level to the upper level. It includes all operations and delays of vessels and locks from the moment vessel entrance into the ship lock zone at the lower level.

Sub-model 2 is the locking process of vessels from the upper level to the lower level. It includes all operations and delays of vessels and locks from the moment vessel entrance into the ship lock zone at the upper level.

Sub-models 3 and 4 describe control processes of ship locks 1 and 2 during locking from the lower level and include:

- ❖ control of vessels' entering in ship locks 1 and 2 from the lower level
- ❖ water level change in ship locks 1 and 2 without vessels, in cases when there is no queue at the lower level, lower gates 1 or 2 are opened, while vessels at the upper level wait in the queue.

Sub-models 5 and 6 describe control processes of ship locks 1 and 2 during locking from the upper level and include:

- ❖ control of vessels' entering in ship locks 1 and 2 from the upper level
- ❖ water level change in ship locks 1 and 2 without vessels, in cases when there is no queue at the upper level, upper gates 1 or 2 are opened, while vessels at the lower level wait in the queue.

Sub-models 7 and 8 describe control processes of vessels re-grouping in the queues at the lower and upper levels. Re-grouping depends on: priority level, order of arrival and area size ($L \times B$) which vessel occupies in the lock chamber. Sub-model 9 represents the duration of the simulation experiment.

❖ EVALUATION OF THE SIMULATION MODEL

Evaluation of the developed simulation model included determination of the model validity and the model testing [2], [3]. Determination of the model validity was done up to the level of predictability. Predictive model validity is a stricter level of evaluation that is related to the model ability to be used to predict the situations that are not observed and studied on the real systems. That level was tested with simulation experiments. In the simulation experiments the traffic density was altered in both directions and system reactions were observed.

The model testing was done from the beginning of the real system modelling and includes:

- ❖ application of specialized language (GPSS) to realize the simulation program
- ❖ validity and accuracy testing of the simulation model (verification of static and dynamic properties of the model)
- ❖ correctness testing of the model to generate different distributions of input variables and system parameters.

Control of the simulation model has determined if there is a match between behaviour of program and model. The developed simulation model completely fulfils presented requirements and criterions, and such can be used in simulation experiments for capacity determination and change in density of traffic on certain real system.

❖ CONCLUSION

Navigation in ship lock zones, as a part of system of navigation on inland waterways, apart other things, is characterized by limited capacity and the need to use information-control systems. Capacity presents one of the most important characteristic of each waterway, especially ship lock. The organization of traffic on the observed real system has significant influence on the capacity.

The developed simulation model of the technological process of ship locking gives a number of data, like vessel delays, transit times, resource utilizations, number of vessels in queues and others. The developed model can be applied to planning of vessel traffic control, since they give a possibility of choice of traffic organization that depends on certain conditions. Connections between elements of technological process in presented models have been copied from real system. This allows variation in densities and distribution of all incoming vessels' flows, as well as changes of technical characteristics of ship lock and vessels.

Application of developed simulation models is applicable for planning and decision making in ship locking control. Also, they can be applied to define type of organization of ship locking process. It is possible to do almost unlimited number of simulation experiments. More important, the model's fidelity enables to predict conditions for any future scenarios of interest (e.g., under increasing traffic volumes), and to answer various other "what-if" questions [8].

High-fidelity simulation models of ship locking process consisting of the entire vessel classes as well as level of priority, weather and waters conditions can be easily developed. Significant extensions of model can be made by adding new segments. Such extended simulation model includes the following: application of control rules, ability to monitor the influence of large vessels on waterway capacity.

Also, further research should focus on problems how to define optimal density of traffic for given conditions. To solve this problem it is necessary to introduce the term "level of service" (as a qualitative measure). Determination of the optimal density requires application of certain optimization methods in order to achieve certain levels of service with defined conditions and relevant parameters.

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