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Management of Lock Navigation to Reduce Queuing

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Preliminary communication

Automation of navigation at sea has partly been provided for with the use of integrated navigation bridge − INB. The functioning of INB is supervised by the officer who also takes the final decision during navigation. The complete automation of navigation can be improved by upgrading the existing equipment on board modern ships. To provide for automation of inland navigation all the necessary infrastructure can be installed in the immediate vicinity of the ship. Such an infrastructure includes special transmitters, receivers and measuring instruments networked with the ship's instruments. From that aspect, limitedness of waterways is considered to be their advantage.

Ship's navigation can be managed by a system of networked computers containing programs required for conducting a ship.

In this paper the authors use continuous Petri nets for modelling and simulation of ships' navigation through a system of locks without queuing.

Keywords: *automation of navigation, INB, inland navigation, Petri nets, safety*

Upravljanje plovidbe prevodnicom u cilju smanjivanja redova čekanja

Prethodno priopćenje

Automatizacija pomorske plovidbe djelomično je riješena uporabom integriranog navigacijskog mosta-INS. Rad INS-a nadzire časnik koji i donosi konačnu odluku tijekom plovidbe. Potpunu automatizaciju plovidbe moguće je poboljšati nadogradnjom postojeće opreme na suvremenim brodovima. Za potrebe automatizacije plovidbe unutarnjih plovnih putova sva potrebna infrastruktura može se postaviti u neposrednoj blizini broda. Takva infrastruktura uključuje posebne odašiljače, prijamnike i mjerne uređaje umrežene s brodskim uređajima. Sa toga gledišta, ograničenost plovnih putova drži se njihovom prednošću.

Plovidbom broda može upravljati sustav mrežno povezanih računala koji sadrži programe potrebne za vođenje broda.

U ovom radu autori koriste kontinuirane Petrijeve mreže za modeliranje i simuliranje plovidbe brodova kroz sustav prevodnica bez redova čekanja.

Ključne riječi: *automatizacije pomorske plovidbe, integrirani sustav mosta, Petrijeve mreže, plovidba unutarnjim plovnim putovima, sigurnost*

1 Introduction

Automation of navigation at sea has partly been provided for with the use of integrated navigation bridge − INB [1, 2, 3, 4]. INB is a bridge containing electronic navigation instruments mutually networked with *the ship's central computer* (*sc*). The role of the ship's central computer is:

- Surveillance of electronic navigation devices
- Processing data gained from electronic navigation devices
- Processing data gained from other instruments
- Exchange of data with the navigator.

In case of a device failure, the central INB computer informs the navigator about the failure of the device. The computer program functions so as to provide the navigator only with the information necessary for a certain leg of the journey. The information of minor importance is neglected. The *sc* processes the data and provides calculations that will facilitate the decision, but the final decision is taken by the navigator. Other computers supervising ship's systems are connected to the *sc*. Such are for example computers for work and supervision of the engine-room, computers for work and supervision of cargo, computers of the fire-detection system and alike. Functioning of navigation aids is also possible without the *sc*. SOLAS requires integrated bridge to be provided with the option of all devices functioning separately, i.e. without exchanging data with the *sc*. Such an option is used for the case of *sc* failure [5]. With this system, the officer is an unavoidable factor taking final decision in any situation due to ship's navigation.

In case the officer were excluded as the factor deciding on the solution of a situation in the course of navigation, a complete automation of ship's systems and remote supervision of the ship would be necessary. In such a case the officer would supervise ship's systems in order to avoid the occurrence of an unwanted situation during device breakdown. Complete automation of navigation can be enhanced with upgrading of the existing equipment on board modern ships. To meet the needs of complete automation of inland navigation all the necessary infrastructure can be installed in the immediate vicinity of the ship. Such an infrastructure includes special transmitters, receivers and measuring instruments networked with the ship's devices. From that aspect, limitedness of waterways is considered to be their advantage.

Ship's navigation can be conducted by a computer containing computer programs required for conducting the ship. It would be provided with all the necessary data for navigation from the shore-based computer. It would in this way also be provided with the instructions for navigation, destination, course, speed, and alike. The shore-based computer would supervise the shipboard computer.

Certain areas of navigation should be divided into zones. Each computer would manage a certain navigation zone. A *navigation zone computer (zc)* should be networked with other navigation zone computers and with *the central shore-based computer (cc)*. Its role would be supervision and conduct of ships with automatic zone navigation facility (Figure 1). Hierarchically distributed computer system (Figure 1) is comprised of a computer network distributed over a large area so that single computers manage hierarchically lower computers. Thus, the shipboard central computer is in certain parts subordinated to a zone computer that is hierarchically at a higher level.

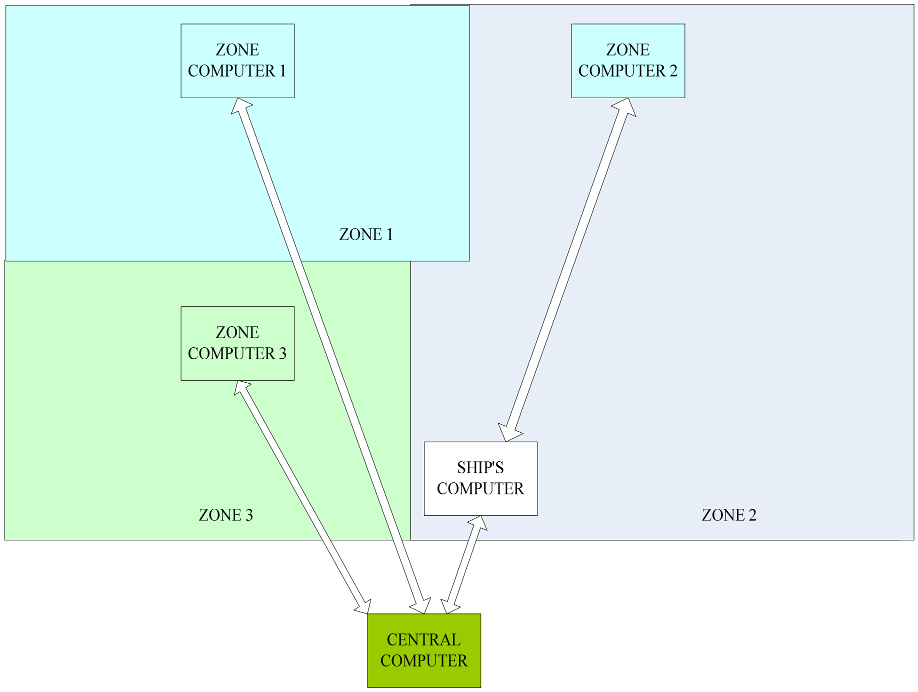

Figure 1 **Hierarchically distributed computer system of ship management**
Slika 1 **Hijerarhijski distribuiran računalni sustav upravljanja broda**

Navigation zone computer (zc) should have such characteristics as to be able to:

- Receive information from all shipboard computers within range
- Process the data acquired
- Compare the data from all shipboard computers
- Forward information and instructions for navigation to shipboard computers
- Forward information to the central shore-based computer.

The central shipboard computer (sc) would be the main computer of the integrated navigation bridge − INB. It should have such characteristics to be able to:

- Receive and process information gained from all the system computers and ship's devices
- Exchange information with the shore-based zone computer *(sc)*
- Process the data from the shore-based zone computer *(zc)* and forward tasks to the rest of the ship's computers
- Receive and compare information from the shore-based central computer *(cc).*

In case of the *sc* breakdown and of necessity of increased reliability of a navigation zone computer, the *zc* substitutes it with a *beck-up ship's computer*. Therefore, it is necessary for the ship's system to be provided with two central computers:

- One in conducting the ship
- The other being an active back-up**.**

Active back-up means simultaneous performance of tasks. In case of a breakdown, the back-up active computer would take over the conduct of the ship without any interruption. Functioning of only one onboard computer (back-up) would imply increased navigator's attention. In case of further failures navigation watch-guard officer should switch off the automatic system and conduct the ship manually.

The shore-based central computer (cc) would supervise and coordinate the functioning of navigation zone computers. It must be provided with the facility of receiving, supervising data and calculations of the shore-based zone computer. In the case of error of the shore-based zone computer it has to forward new data to the shore-based zone computer. The *cc* should also be provided with the facility of switching it off in case of failure. Then the *cc* excludes from the network the shore-based zone computer and redirects the data to the nearest or back-up zone computer.

Such a system of automated conducting of ships (Figure 2) does not exclude human supervision of the system. Moreover, in case of the system breakdown, it must be provided with the facility of bridging over to the manual system of conducting the ship and managing the traffic.

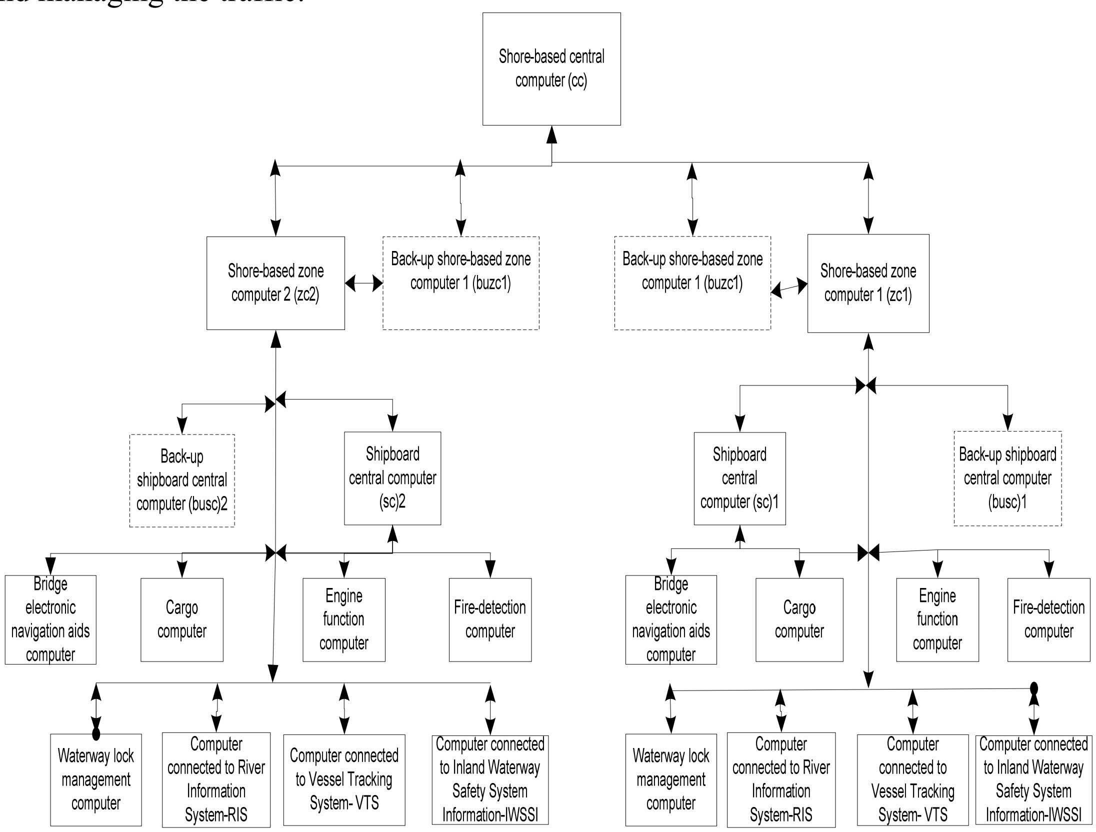

Figure 2 **General illustration of computer network in automatic navigation system**
Slika 2 **Opći prikaz mreže računala u sustavu automatske plovidbe**

The ship's characteristics such as ship's length, beam, height, capacity, draught, speed, manoeuvring features and alike have to be supplied to the shipboard central computer. On the basis of the data exchanged with the shore-based zone computer the shipboard computer will adjust the ship's course, speed, etc.

2 Simulation of lock navigation using Petri net

A lock is a system consisting of canals and basins separated by gates. Their role is to overcome differences in heights of waterways. They are used for water level differences up to about 35 m. It is considered reasonable to use locks in overcoming water level differences up to 70 m [6]. They are used to avoid conducting the ship on water slopes. In this way time and energy are saved. Functioning of lock in Figure 3 can be explained through the following steps:

- lock 1 of basin 1 is opened, lock 1 is opened by lowering it to the height of 0.1 m from the bottom,
- ship 1 enters basin 1,
- lock 1 is closed by raising it to the height of 6 m,
- raising the water level in the lock basin for 2.7 m above the previous water level,
- lock 2 is opened by lowering the lock 2 to the height of 0.1 m from the bottom,
- ship 1 crosses into basin 2,
- lock 2 is closed by raising the lock 6 m above the bottom,
- raising the water level in basin 2 by the difference in height of 2.7 m and simultaneous lowering the water level in basin 1 to the level of 3 m (preparation for ship 2),
- lock 3 is opened by lowering it to the height of 0.1 m from the bottom, lock 1 is opened by lowering it to the height of 0.1 m,
- ship 1 leaves basin 2,
- ship 2 enters basin 1.

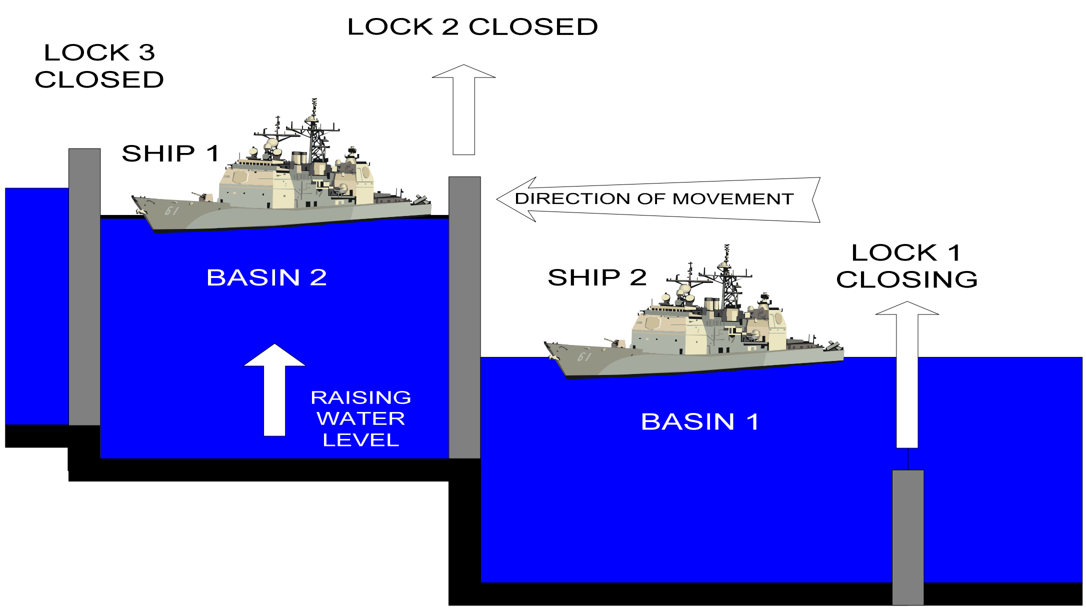

Figure 3 **Schematic side view of lock**
Slika 3 **Shematski bočni presjek prevodnice**

In case the lock is engaged the automated navigation system may advise:

- reducing speed and adjusting time of arrival to the lock,
- reducing speed and waiting,
- selecting an alternative waterway if available.

Reducing speed and adjusting time of arrival is advised in order to:

- save fuel due to engine running at reduced rate,
- avoid queuing for the lock at anchorage.

The lock computer manages the moves within the lock. The instruction on the necessary speed reduction is given by the zone computer. It receives information on the number of ships at the anchorage from the lock computer. Every 10 km the speed of approaching ships is checked. The recalculated new speed is forwarded to the shipboard central computer and shore-based central computer.

The time of queuing for the lock can be limited. The time limit is calculated taking into consideration the ship's *Estimated Time of Arrival − ETA* and average sailing speed.

x_{gr} is the time limit of possible waiting for the lock with regard to the ship's ETA, and t is permitted time of waiting for the lock with regard to ETA.

Taking into consideration t and x_{gr} it follows that:

$t \le x_{gr}$ reducing speed and adjusting time of arrival to the lock is advised and

$t > x_{gr}$ choosing an alternative waterway possibly avoiding the lock is advised.

Occupied lock may be the result of:

- increased traffic (queuing for passage),
- breakdown,
- maintenance.

Increase in traffic at the lock will depend on the number of ships at the entrance to the lock. The number of ships to enter the lock in a non-automated system is considered stochastic [7]. Stochasticity of events is reflected in ships arriving in random intervals. Such arrivals observed within a determined time interval can result in the non-engaged lock, which can be followed by long queuing to traverse it. The number of ships at the entrance to the lock at the instant t can be expressed as follows:

$$K(t) = \overline{K}(t) + \varepsilon_n(t) \qquad (3)$$

$K(t)$ is the number of ships in front of the lock at the instant t,

$\overline{K}(t)$ is the arithmetic mean of $K(t)$, and

$\varepsilon_n(t)$ deviation from the mean $\overline{K}(t)$.

The magnitude of $\varepsilon_n(t)$ is expressed by the probability of the occurrence.

Idling time T_k due to a breakdown can be expressed as:

$$T_k = \lambda_k * T_l * T_x \qquad (4)$$

λ_k is the frequency of breakdowns in the unit of time,
T_1 time of period observed, and
T_x average time of breakdown duration [8].

Idling time due to maintenance T_o can be expressed as:

$$T_o = \lambda_o * T_1 * T_x \qquad (5)$$

λ_o the frequency of maintenance in the unit of time,
T_1 time of period observed, and
T_x average time of repair duration.

The total lock idling time T_u due to maintenance and breakdown can be expressed as follows:

$$T_u = T_o + T_k \qquad (6).$$

The time required for each ship to transit the lock T can be expressed as:

$$T = T_s + t_m + T_u \qquad (7)$$

T_s is the time of lock system operation,
t_m is the time of ship's manoeuvring in the lock.

Ship's queuing time for transit T_b can be expressed as follows:

$$T_b = \sum_{i=1}^{n} K(t) * T_i + \sum_{i=1}^{n} T_{oi} + \sum_{i=1}^{n} T_{ki} \qquad (8)$$

$K(t)$ is the number of ships queuing for transit before ship b,
T_i is the time required for each ship to transit the lock,
n is the number of locks during the travel.

In the case of the occupied lock or a queue at the lock entrance, the lock management computer should warn the zone computer that the lock is not available. The zone computer forwards the information to the ship's central computer and issues an order to adjust the speed. In that manner queuing at anchorage is avoided and fuel is saved. The adjusted ship's speed to arrive to the free lock v_b is calculated according to the well-known formula for average speed:

$$\bar{v}_b = s / T \qquad (9),$$

where s is the distance to go to the lock entrance,
T is the time required for the lock to be free.

Providing the current ship's speed is higher than the limit speed, i.e. $v_b \geq v_{gr}$, the ship will proceed at the speed v_b. The limit speed is considered to be the minimum possible speed that ensures the safe passage of the ship, or ability to manoeuvre and alike. If $v_b < v_{gr}$, the ship will proceed at the limit speed. In that case the ship will arrive earlier to the lock and will spend time queuing in front of the lock (t_t):

$$t_t = s/(v_b - v_{gr}) \quad (10).$$

In case the lock is free the system timely warns the lock about the ship's arrival. The system has to adjust the ship's speed to the conditions limited to manoeuvre and introduce the ship into the lock.

The zone computer should follow the algorithm of decision-making (Figure 4) for calculation of speed, selection of waterway, and surveillance of traffic within the lock. This kind of system is considered to be a complex, hybrid system consisting of continuous and discrete processes. For modelling and simulation of this traffic problem in this article the hybrid Petri nets are used. As a difference from the common Petri nets they have two types of places and transitions: discrete and continuous. The discrete places can have a discrete number of designations, while the continuous places have a real number of designations. Besides the standard arcs connecting places with transitions, the hybrid Petri nets also have inhibitor arcs (arcs with circles behind the arrow) that block certain transitions [9].

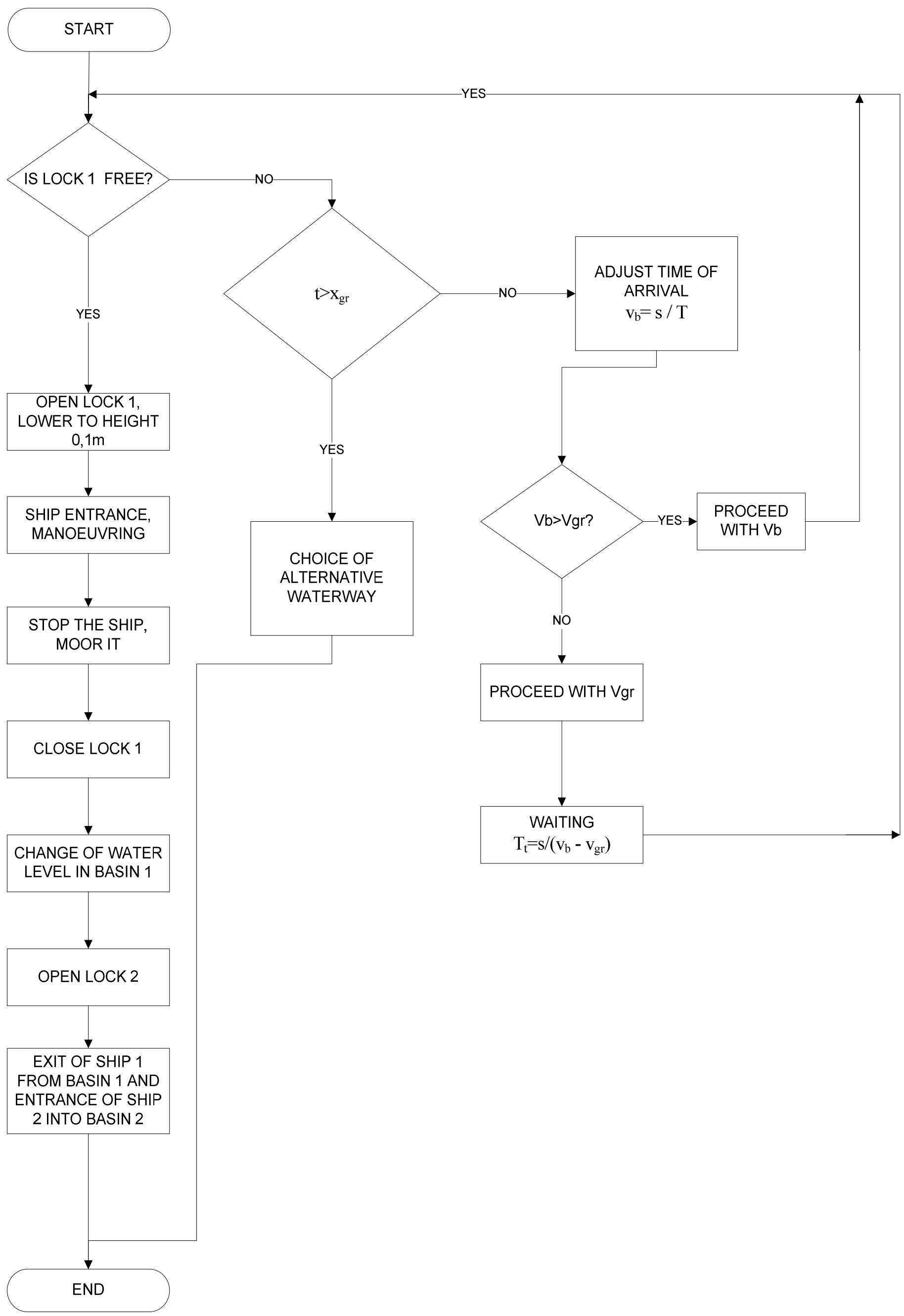

Figure 4 **General management algorithm**
Slika 4 **Opći algoritam upravljanja**

3 Modelling and simulation of lock using hybrid Petri net

The model of a lock made using a hybrid Petri net is shown in Figure 5. The model consists of 18 discrete places and 5 continuous places as well as 15 discrete transitions and 10 continuous transitions. The places in the Petri net designate states, and transitions designate occurrences causing changes of states. The theory and the formal mathematical description of hybrid Petri nets can be found in [9]. In Table 1 the meanings of different places and transitions are shown.

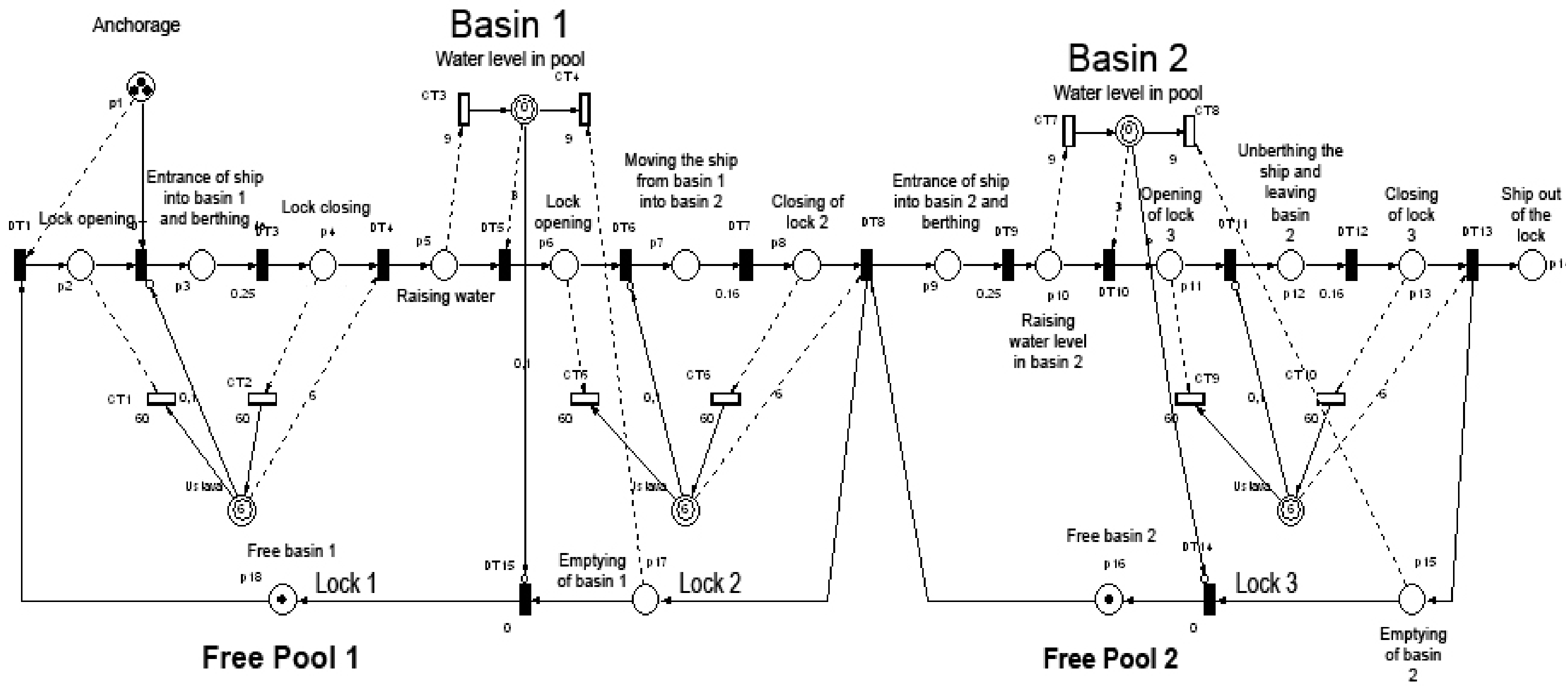

Figure 5 **Hybrid Petri net of the lock, [10]**
Slika 5 **Hibridna Petrijeva mreža prevodnice, [10]**

Table 1 **Meaning of discrete places and transitions for the lock Petri net**
Tablica 1 **Značenje diskretnih mjesta i prijelaza za Petrijevu mrežu prevodnice**

Discrete places	***Meaning of discrete places***
P1	*Anchorage*
P2	*Opening of lock 1*
P3	*Entrance of ship into basin 1 and berthing*
P4	*Closing of lock 1*
P5	*Raising water level in basin 1*
P6	*Opening of lock 2*
P7	*Moving the ship from basin 1 into basin 2*
P8	*Closing of lock 2*
P9	*Entrance of ship into basin 2 and berthing*
P10	*Raising water level in basin 2*
P11	*Opening of lock 3*
P12	*Unberthing the ship and leaving basin 2*
P13	*Closing of lock 3*
P14	*Ship out of the lock*
P15	*Emptying of basin 2*
P16	*Free basin 2*
P17	*Emptying of basin 1*
P18	*Free basin 1*
Continuous places	***Meaning of continuous states***
C1	*Height of lock 1*
C2	*Water level in basin 1*
C3	*Height of lock 2*
C4	*Water level in basin 2*
C5	*Height of lock 3*
Discrete transitions	***Meaning of discrete occurrences***
DT1	*Basin 1 ready, start opening lock 1*
DT2	*Lock 1 opened (height 0.1 m from bottom)*
DT3	*Time lapse of 15 minutes for berthing*
DT4	*Lock 1 closed (height of water 6 m)*
DT5	*Water level in basin 1 reached 3 m*
DT6	*Lock 2 opened (height 0.1 m from bottom)*
DT7	*Time lapse of 10 min for unberthing and moving the ship*
DT8	*Lock 2 closed (height 6 m)*
DT9	*Time lapse of 15 minutes for berthing*
DT10	*Water level in basin 2 reached 3 m*
DT11	*Lock 3 opened (height 0.1 m)*
DT12	*Time lapse of 10 min for ship's unberthing and leaving*
DT13	*Lock 3 closed (height 6 m)*
DT14	*Basin 2 empty*
DT15	*Basin 1 empty*
Continuous transitions	***Meaning of continuous occurrences***
CT1	*Open lock 1 at the speed of 0.6 m/min*
CT2	*Close lock 1 at the speed of 0.6 m/min*
CT3	*Fill basin 1 at the speed of 0.15 m/min*
CT4	*Empty basin 1 at the speed of 0.15 m/min*
CT5	*Open lock 2 at the speed of 0.6 m/min*
CT6	*Close lock 2 at the speed of 0.6 m/min*
CT7	*Fill basin 2 at the speed of 0.15 m/min*
CT8	*Empty basin 2 at the speed of 0.15 m/min*
CT9	*Open lock 3 at the speed of 0.6 m/min*
CT10	*Close lock 3 at the speed of 0.6 m/min*

The hybrid Petri net in Figure 5 represents continuous and discrete processes taking place during functioning of the lock shown in Figure 3. The model in Figure 5 can be described in words as follows:

The condition to let the ship leave the anchorage (P1) to enter the basin 1 is free basin 1, and the level of water equal to the level of the river. After the lock computer identifies the basin 1 to be free (marking in place P18), the computer sends an order to the control system to start the engine of the lock 1. The lock 1 is lowered from the closed position (height 6 m) to the opened position (height 0.1 m above the bottom) at the speed of 0.6 m/min. The lock 1 height sensors emit the signal that the lock 1 is lowered (transition DT2 is fired) and the lock computer approves the entrance of the ship into the basin 1 (marking in place P3). In the P3 place there is 15-minute waiting until the manoeuvre of ship entrance into the basin 1 and berthing are completed. After this time lapse state P4 is activated in which the lock computer starts the lock motor that raises the lock 1 to the level of 6 m. After that, in the place P5 electric motor pumps filling the basin 1 at a speed of 0.15 m/min. are started. When the water level sensors in the basin 1 detect that the difference in levels of 2.7 m is achieved (which corresponds to the water height of 6 m) and that it is equal to the water level in the basin 2, the procedure of opening (lowering) of the lock 2 follows at the same speed as with the lock 1. After the lock 2 is opened, the state P7 is activated in which moving of the ship from the basin 1 into the basin 2 is accomplished. The necessary time is 10 minutes. After that, simultaneous emptying of the basin 1 (place P17) and filling of the basin 2 (place P10) take place. After the basin 1 is emptied, state P18 is activated, the computer gives the signal that the basin 1 is free and if there are other ships at the anchorage the procedure of lowering the lock 1 and entrance of a new ship into the basin 1 is repeated again as described above. Independent of the control procedure that the computer performs for the basin 1, detection of water level in the basin 2 is performed. After the water level in the basin 2 is raised for 2.7 m (3.3 is the initial water level, 6.0 m is the water level of the full basin), the lock 3 (P11) is opened, followed by unberthing of the ship and leaving the lock (P13 and P14).

The heights of the locks 1, 2 and 3 as well as the basins 1 and 2 were modelled with continuous places C1-C5. The graphic representation of the simulation is given in the graphs 1-7**.** They were recorded in the period of 7.1 h from the beginning of the simulation.

The simulation in Figure 6 (graphs 1 to 7) was made with the following initial conditions:

- there are 3 ships at the anchorage
- all basins are free
- all locks are raised
- water level in basin 1 is equal to the water level at the anchorage.

From graph 1 (Figure 6) representing the number of ships at the anchorage (P1) it is visible that the first ship leaves the anchorage 6 minutes after the beginning of simulation, the second ship 1 h 40 min after the beginning of simulation, and the third ship 3 h 30 min after the beginning of simulation. From graph 7 (Figure 6) it is visible that the first ship leaves the lock 2 h 24 min after the beginning of simulation, the second ship 4h 12min and the third 5h 48 min after the beginning of simulation. The graphs “level of lock x“ and “water level in basin x“ represent the continuous process of raising and lowering the levels of locks and basins.

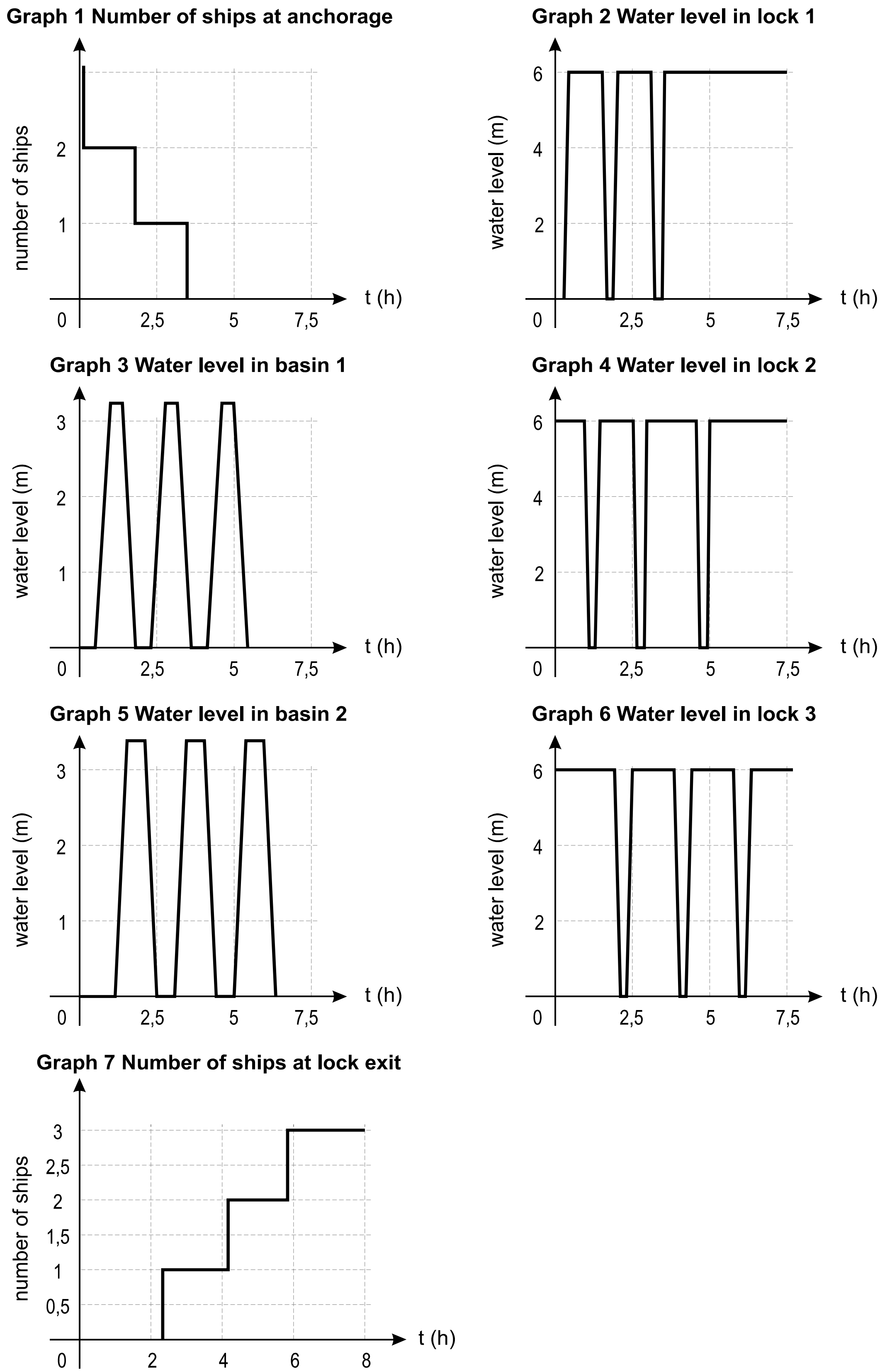

Figure 6 **Parameters from hybrid Petri net simulation of lock, [10]**
Slika 6 **Parametri simulacije prevodnice hibridnim Petrijevim mrežama, [10]**

4 Modelling and simulation of arrival to lock without queuing

With the Petri net in Figure 5 the process related to the lock and, thus, also the algorithm of lock computer control are represented (Figure 4). To avoid queuing at the anchorage it is necessary to control the speed of approaching ships. This task is taken over by the zone computer that continuously receives information on the distance of ships from the lock and information on the current number of ships queuing at the anchorage. In this paper the authors model and simulate the process of controlling the speed of ships approaching the lock, and the aim is to reduce queuing at the anchorage.

Ships' transiting the lock without queuing is a problem that can be modelled and simulated using the hybrid Petri net in Figure 7. From this model the synthesis of the algorithm of controlling the approach of ships without queuing can easily be performed. The expected acceptable result gained by the simulation on the model from Figure 7 would be the arrival of a ship to the free lock and it can be gained by the adjustment of the sailing speed of ships to the conditions at the anchorage. On the basis of the current distance of the ship from the lock and the number of ships queuing at the anchorage, the optimum speed of ships approaching the lock is calculated so that the ships arrive at the anchorage exactly at the time when the lock is available, i.e. without queuing. The idea of controlling is the following: the zone computer starts tracking the movement of ships at the distance close beyond 40 km. At the distance of 40 km from the lock, the zone computer transmits to the ship's computer the permitted speed of approach that was modelled with the speed of firing of the continuous transitions CT1-CT5. The zone computer then corrects the speed of approach to 30, 20 and 10 km from the anchorage depending on the current number of ships approaching and those at the anchorage.

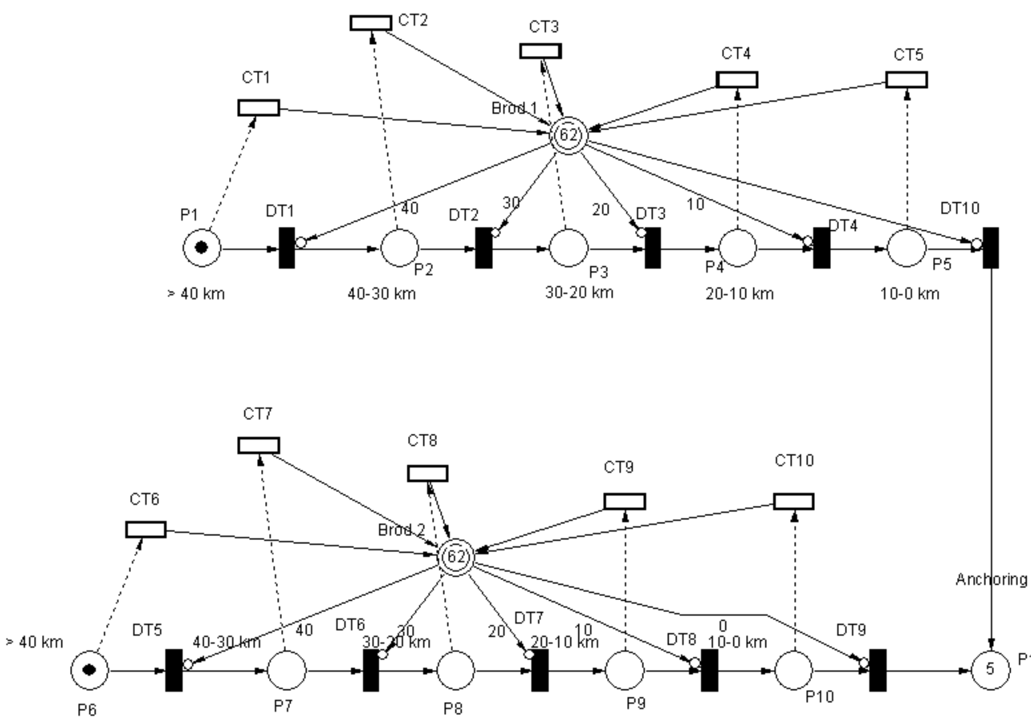

Figure 7 **Model of controlling the approach of ships to the lock without queuing, [10]**
Slika 7 **Model upravljanja dolaskom brodova u prevodnicu bez redova čekanja, [10]**

The model from Figure 7 above represents management of speed of the two ships approaching the lock. For this example it is presupposed that the ships start the approach at a speed of 9 km/h. The approach of ship 1 was modelled by discrete places P1-P5, and that of ship 2 by discrete places P6-P10 (Table 2). The continuous transitions CT1 – CT10 determine speeds of ships in the phase of approaching the lock (Table 2). The simulation was performed with the presupposition that the zone computer adds to the ship 1 the advantage for transition due to ETA and t permitted. In order for the ship to arrive without a loss of time, her speed is the maximum permitted and continuous during the approach. The zone computer calculates the speed of ship 2, and it reduces it so that ship 2 arrives to the lock without queuing. At the same time the zone computer takes into consideration the number of ships at the anchorage and the distance travelled by ship 1. The speed of ship 2 is reduced after each 10 km travelled. Here it has to be born in mind that her $v_b \geq v_{gr}$. In case it is calculated that $v_b < v_{gr}$ the ship will proceed voyage with v_{gr}. v_{gr} will ensure the response of the rudder while maintaining the course. The ships arrive to the anchorage in the following order:

1. Ship 1
2. Ship 2.

The description of all the continuous and discrete transitions of the Petri net in Figure 7 is given in Table 2. The Petri net in Figure 7 is used to model and simulate two ships approaching the lock.

Table 2 **Meaning of continuous and discrete places and transitions of Petri net from Figure 6**
Tablica 2 **Značenje kontinuiranih i diskretnih mjesta i prijelaza Petrijeve mreže sa slike 6**

Discrete places	***Meaning of discrete places***
P1	*Ship 1 distance from the lock > 40 km*
P2	*Ship 1 distance from the lock 30-40 km*
P3	*Ship 1 distance from the lock 20-30 km*
P4	*Ship 1 distance from the lock 10-20 km*
P5	*Ship 1 distance from the lock do 10 km*
P6	*Ship 2 distance from the lock > 40 km*
P7	*Ship 2 distance from the lock 30-40 km*
P8	*Ship 2 distance from the lock 20-30 km*
P9	*Ship 2 distance from the lock 10-20 km*
P10	*Ship 2 distance from the lock up to 10 km*
P11	*Anchorage*
Continuous places	***Meaning of continuous states***
C1	*Distance of ship 1 in km*
C2	*Distance of ship 2 in km*
Discrete transitions	***Meaning of discrete occurrences***
DT1	*Ship 1 distant 40 km*
DT2	*Ship 1 distant 30 km*
DT3	*Ship 1 distant 20 km*
DT4	*Ship 1 distant 10 km*
DT5	*Ship 2 distant 40 km*
DT6	*Ship 2 distant 30 km*
DT7	*Ship 2 distant 20 km*
DT8	*Ship 2 distant 10 km*
DT9	*Ship 2 enters the anchorage*
DT10	*Ship 1 enters the anchorage*
Continuous transitions	***Meaning of continuous occurrences***
CT1	*Speed of ship 1 at the distance of > 40 km*
CT2	*Speed of ship 1 at the distance of 30-40 km*
CT3	*Speed of ship 1 at the distance of 20-30 km*
CT4	*Speed of ship 1 at the distance of 10-20 km*
CT5	*Speed of ship 1 at the distance of up to 10 km*

CT6	*Speed of ship 2 at the distance of > 40 km*
CT7	*Speed of ship 2 at the distance of 30-40 km*
CT8	*Speed of ship 2 at the distance of 20-30 km*
CT9	*Speed of ship 2 at the distance of 10-20 km*
CT10	*Speed of ship 2 at the distance of up to 10 km*

The simulation of the lock model with the hybrid Petri net was performed using *Visual Object Net ver 2.7* software package. The results are shown in graphs 1-3 in Figure 8. The initial state implies 5 ships at the anchorage, and 2 ships approaching (Graph 3, Figure 8). Once the simulation started, the lock computer conducts the process taking the ships from the anchorage over through the lock, while the zone computer manages the approach speed of ships 1 and 2. In case of Ship 1 it is visible that the sailing speed is constant and maximum possible – priority approach Graph 1 (Figure 8). It can be seen from Graph 2 (Figure 8) that Ship 2 will slow down after approaching the lock at a distance of less than 10 km. Her speed will decrease to below 9 km/h. The reason is avoiding the simultaneous arrival to the anchorage with Ship 1. Graph 3 (Figure 8) shows the number of ships at the anchorage. It is visible from Graph 3 (Figure 8) that in the period of 7 h after the beginning of simulation all 5 ships that were at the anchorage will have completed the transit. This is followed by a relatively short time interval in which the anchorage is empty. A further course of events follows the arrivals of Ship 1, and afterwards of Ship 2. There is no queuing of Ships 1 and 2 for the entrance to the lock.

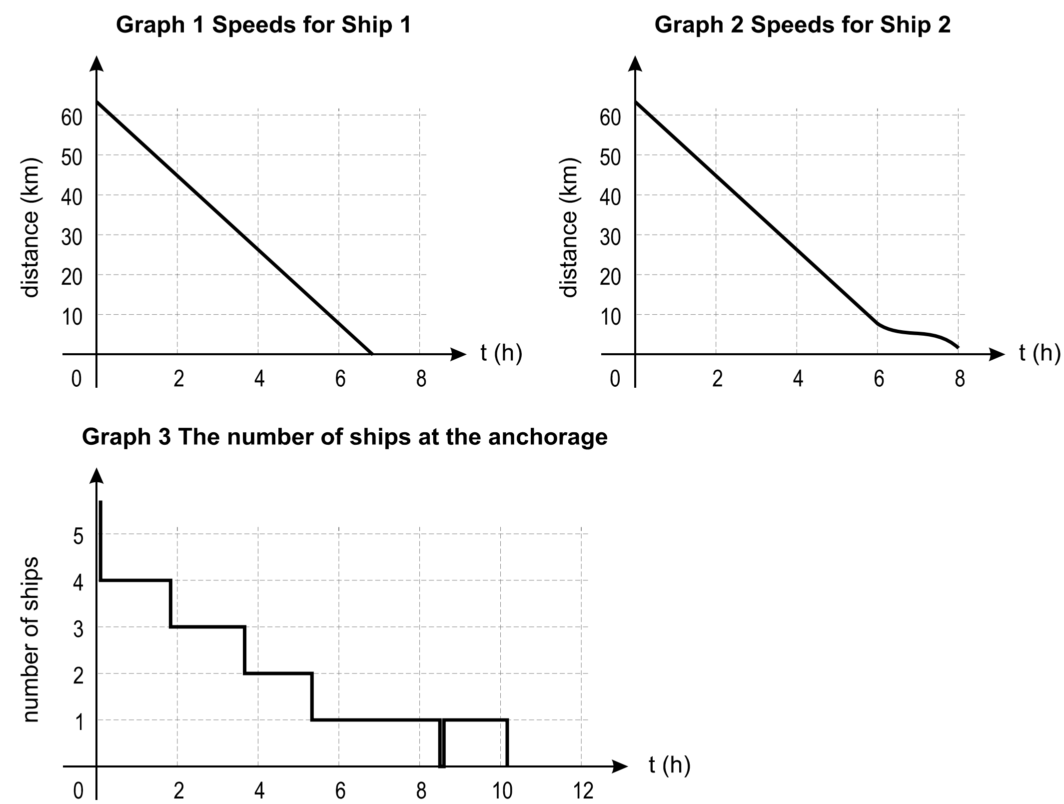

Figure 8 **Parameters from hybrid Petri net simulation of ships at anchorage and waterway, [10]**
Slika 8 **Parametri hibridne Petrijeve mreže za brodove na plovnom putu i sidrištu, [10]**

Conclusion

The application of this kind of system can significantly reduce expenses occurring due to employees' pays. The number of employees on EU inland waterways is considered insufficient against the ever increasing development of the fleet and infrastructure of inland waterways. The number of employees in inland waterway traffic is considered to be falling year after year. The reason is seen as the loss of employment tradition in this industry. Besides the above mentioned, a reduction in the number of inland waterway courses completions is recorded. Therefore, automation of inland waterway navigation can be fostered by a possible decrease in the number of workforce due to little interest for this branch of traffic.

Automation of navigation can be improved by upgrading the existing equipment on board modern ships. An advantage of a possible automation of navigation on inland waterways is seen in the possible installing of all the necessary infrastructure in the immediate vicinity of the ship.

The parameters gained by the simulation using Petri nets are within limits of realistic expectations. Therefore, a conclusion has been reached that this simulation gives satisfactory results.

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