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APPLICATION OF PETRI NETS FOR TRANSPORT STREAMS MODELING

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Abstract. *One of the possible methods for transport stream modeling is by using Petri's nets* [1,2]. *This approach turns out to be very convenient for achieving the desired tasks because of the following reasons: the Petri's nets* [3] *are based on causal-consequence connections found in abundance in transport problems and the graphical representation by means of the net elements is easily percieved by man, i.e. there an easy way of visualization of the transpot problem under consideration. Examples will be given of how transport problems are modeled.*

1. INTRODUCTION

Intermodal transport represents a consecutive traffic of loads by two or more types of transport in one and the same transport unit or vehicle without the necessity of reloading when changing the transport type [4]. In a broader sense the concept of "intermodal transport" is used for describing a transportation system with using two or more types of transport for the carriage of one and the same transport unit or vehicle within the framework of the complex transport chain (door to door) without loading-unloading operations [5]. The points for load delivery between two types of transport occupy an important place in the intermodal transport (IMT) chain.

Ports represent a special type of reloading points. Their specific activity is determined by the hydrometeorological conditions in the area, the existing port infrastructure and its connection with the national infrastructure. The ports are the links between land and marine transport. The IMT realization requires that the ports should possess specialized wharf places equipped with the respective technical utilities and storage area [6]. The period when the load is waiting to be transferred to the next type of transport represents an interruption in the transport chain. The decreasing of the duration of this delay leads to

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minimization of the total transportation time of the load along the whole chain. Such an interruption of the chain in the ports is possible in the following cases:

Case 1. The load delivered by land transport has arrived at the port (the specialized wharf) but the ship is missing. In this case the period for realizing the transportation process increases with the time necessary for waiting of the ship. During this period the load is kept in the wharf storehouse (terminal) and this increases the transport expenses.

Case 2. The ship is alongside the quay but the road transport vehicle has not arrived yet. In this case the following two options are possible:

– the ship waits for the load arrival;

– the ship leaves the port without waiting for the load. In this case the load will have to wait for the next ship.

Case 3. The two mutually interacting types of transport are available in the port area but the hydrometeorological conditions in the region of the port do not allow the transport vehicle processing.

Case 4. The two transport types occupy their places at the quay simultaneously and their processing is started – this is the optimal variant for IMT since the time of stay (delay) in the transport chain coincides with the time for realizing the cargo transshipment activities at the port.

2. PETRI NET PRESENTATION

A net of Petri consists of four elements:

– a set of positions $P = \{ p_i, i=1,2,...,n\}$,

– a set of transitions $T = \{ t_j, j=1,2,...m\}$

– an input function I

– an output function O

The input function I represents the transition t_j in a set of positions $I\ (t_j)$, named input positions of the transition. The output function O represents the transition t_j in a set of positions $O\ (t_j)$, named input positions of the transition.

The sets of positions and transitions do not intersect each other: $P \cap T = \emptyset$.

The following designations are introduced for the graphic representation of Petri's nets:

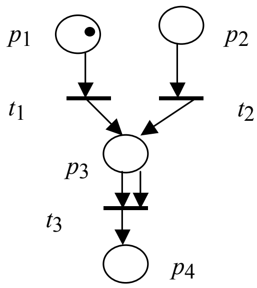
— lines for the transitions,

○ circles for the places (positions), and

⟶ pointed arcs for the relation elements, i.e. for the input and output functions.

The mark is a basic element in the nets of Petri. The marks are assigned to the positions. The quantity and situation of the marks can be changed during the net development. Marking in Petri's nets is a function, which assigns an integer non-negative number to any place in the net: $M : P \rightarrow N$.

A single net for each of the above-mentioned cases as well as a generalized model for all situations can be developed. The net corresponding to Case 1. is depicted in Fig. 1. Here and in the following figures one denotes by p_i, $i = 1,2,...,n$, while $t_j, j = 1,2,\ldots m$.



p_1 – land transport vehicle
p_2 – ship
p_3 – port
p_4 – open sea
t_1 – movement of the land transport vehicle to the port
t_2 – movement of the ship to the port
t_3 – processing and leaving the port

Fig. 1.

The net corresponding to Case 2. is more complicated because there are two sub-options in this variant, that are introduced by additional places as depicted in Fig. 2.

The realization of a given condition is noted by a dot. In the considered case there is a dot in p_2, which means that the ship is in the port vicinity. After execution of the transition t_2 the ship is already situated in the port. There is no mark in p_1, which shows that the land transport vehicle is not found in a certain area around the port. Since there is one dot in p_3, the transition t_3 cannot be realized. The marks present in *the clock* (p_6) memorize the minutes or hours of the stay. For example, it is admissible that the ship will wait for the cargo 3 hours at the most, after which the ship should leave the port even without freight. Then the place p_6 is noted by 3 marks (one per each hour of sojourn). Transitions t_4 and t_5 will be executed 3 times and if by then no mark appears in p_1, the only active transition will be t_6, which means that the ship will leave the port without cargo. If the land transport vehicle arrives after the first execution of t_4 and t_5, its mark will be transferred in p_3, which will lead to the activation of t_3 and reloading of the ship will take place and the vessel will leave the port with cargo.

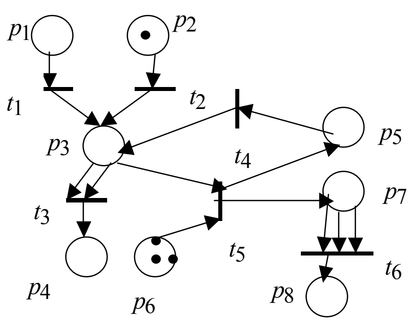
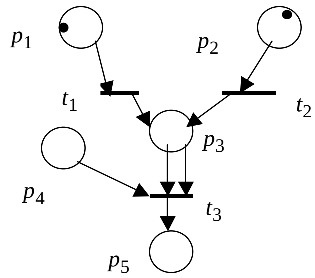


Fig. 2.

p_1 – land transport vehicle
p_2 – ship
p_3 – port
p_4 – open sea
p_5 – additional place
p_6 – clock
p_7 – additional place for time recording
p_8 – open sea
t_1 – t_1 – movement of the land transport vehicle to the port
t_2 – movement of the ship to the port
t_3 – processing and leaving the port
t_4, t_5 – related with time recording
t_6 – leaving the port without cargo (without processing)

In Case 3. a place taking into account the meteorological conditions should be envisaged in the PN model. This is expressed in Fig. 3 where p_4 is introduced for these purposes.

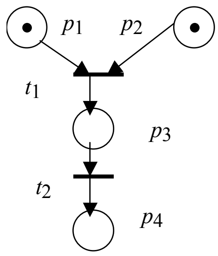


p_1 – land transport vehicle
p_2 – ship
p_3 – port
p_4 – hydrometeorological conditions
p_5 – open sea
t_1 – movement of the land transport vehicle to the port
t_2 – movement of the ship to the port
t_3 – processing and leaving the port

Fig. 3.

Under favorable hydrometeorological conditions place p_4 is noted by one mark and only then the transition t_3 could be executed, i.e. the cargo could be processed without any problems and the ship could leave the port. In case of necessity a clock could be introduced here too to record the time of sojourn of both vehicles because of the bad hydrometeorological conditions.

In the case of the most favorable variant the model composed by a Petri's net is most simple, because the ship and the land transport vehicle occupy their places at the quay simultaneously and the their processing is started immediately.



p_1 – land transport vehicle
p_2 – ship
p_3 – port
p_4 – open sea
t_1 – movement of the land transport vehicle to the port
t_2 – processing and leaving the port

Fig. 4.

The net of Petri describing the above four cases represents a situation model, which could be used in a ready form in more complex situations. The net is shown in Fig. 5. The places (positions) in this net have the following designation: p_1 – ship, p_2 – land transport vehicle, p_3 – suitable hydrometeorological conditions, p_4 – ship leaving the port with cargo, p_5, p_6, p_7 – awaiting, p_8 – ship leaving the port without cargo.

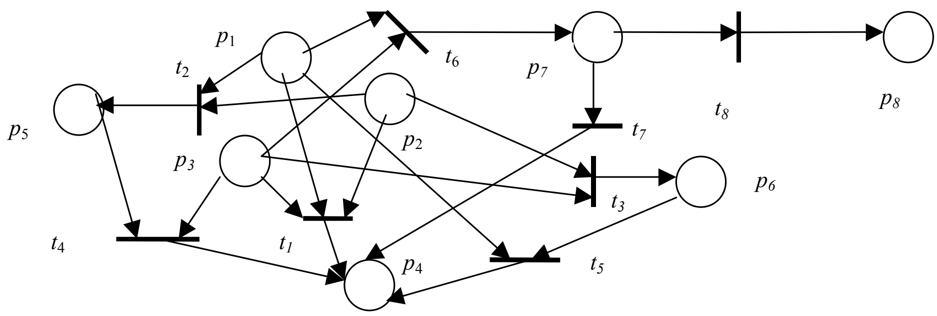


Fig 5.

The presence of a mark in a given place means that the corresponding condition is available. Thus for example, if there are marks in p_1, p_2 and p_3, this will mean that both types of transport are found at the quay place and the hydrometeorological conditions allow their processing. As a result transition t_1 is executed and the ship leaves the port with cargo.

3. Transport flow analysis using the method of matrix equations

One transition is executed only when it is permitted. The transition is permitted only if all of its input positions contain a number of marks not less than the number of arrows (arcs). That means, the state of a net is determined by its marking. The execution of a transition changes the state of the net by altering its marking, which represents a function of alteration δ. This function is called a function of the subsequent state. It is designated in the following manner**:**

$$\delta = N * T \rightarrow N. \tag{1}$$

Two sequences are obtained in the case of changing for the mark position: sequence of markings (μ', μ'', μ''', …) and sequence of transitions, which are executed (t_{j0}, t_{j1}, t_{j2}, …). They are connected with the following relation:

$$\delta(\mu^{\kappa}, t_{jk}) = \mu^{k+1}. \tag{2}$$

If the sequence of transitions and the initial marking are available it is easy to obtain the final marking and if the sequence of markings is known, it is easy to obtain the sequence of transitions.

Alternatively with respect to the definition of Petri's nets in the form (P, T, I, O) the matrices $\mathbf{D}^-$ and $\mathbf{D}^+$ appear, which represent the input and output functions. Each matrix has m rows (each row corresponds to one transition) and n columns (a column per each position). The matrix $\mathbf{D}^-$ is a function γ for inputs in the transitions, $\mathbf{D}^-[j, i] = \boldsymbol{\gamma}(p_i, I(t_j))$, and the matrix $\mathbf{D}^+$ - for outputs $\mathbf{D}^+[j, i] = \boldsymbol{\gamma}(p_i, O(t_j))$.

The definition for a net of Petri written in a matrix form looks like this: (P, T, $\mathbf{D}^-$, $\mathbf{D}^+$). Let $\mathbf{e}[j]$ be an m-vector containing nulls except for the j-th component. The t_j transition represents an m-dimensional vector $\mathbf{e}[j]$. Now transition t_j in the vector marking $\boldsymbol{\mu}$ is permitted when $\boldsymbol{\mu} \geq \mathbf{e}[j]$. As a result of execution of transition t_j in marking $\boldsymbol{\mu}$, $\mathbf{D}^-$ is written in the following manner

$$\delta(\mu, t_j) = \boldsymbol{\mu} - \mathbf{e}[j] \cdot \mathbf{D}^- + \mathbf{e}[j] \cdot \mathbf{D}^+ = \boldsymbol{\mu} + \mathbf{e}[j] \cdot (-\mathbf{D}^- + \mathbf{D}^+) = \boldsymbol{\mu} + \mathbf{e}[j] \cdot \mathbf{D}, \tag{3}$$

where $\mathbf{D} = \mathbf{D}^+ - \mathbf{D}^-$ is the ingredient matrix of the change (the incident matrix). Then we have for the activation of the transition sequence $\sigma = \{ t_{j1}, t_{j2}, \ldots t_{jk}\}$:

$$\delta(\mu, \sigma) = \delta(\mu, t_{j1}, t_{j2}, \ldots t_{jk}) = \boldsymbol{\mu} + \mathbf{e}[j_1] \cdot \mathbf{D} + \mathbf{e}[j_2] \cdot \mathbf{D} + \ldots + \mathbf{e}[j_k] \cdot \mathbf{D} = \tag{4}$$

$$= \boldsymbol{\mu} + (\mathbf{e}[\mathrm{j}_1] + \mathbf{e}[\mathrm{j}_2] + \ldots + \mathbf{e}[\mathrm{j}_\mathrm{k}]) \cdot \mathbf{D} = \boldsymbol{\mu} + \mathbf{f}(\sigma) \cdot \mathbf{D}.$$

The vector $\mathbf{f}(\sigma) = \mathbf{e}[j_1] + \mathbf{e}[j_2] + \ldots + \mathbf{e}[j_k]$ is called the vector of activation of the sequence $tj_1, tj_2, \ldots tj_k$. The i-th element of the vector $\mathbf{f}(\sigma)$, $\mathbf{f}(\sigma)i$ –is the number of activation of the transition tj in the sequence $t_{j1}, t_{j2}, \ldots t_{jk}$. Consequently the vector of activation is a vector with non-negative integers. The development of the matrix theory represents an instrument for solving the accessibility problem. Let us suppose that marking **μ'** is accessible from marking **μ**. Then a sequence σ must exist for activation of transitions, which brings marking **μ** in **μ'**:

$$\mu' = \mu + x \cdot \mathbf{D}\,. \tag{5}$$

In the case **μ'** is accessible from **μ**, the equation has a solution for **x** ≡ **f**(σ) as non-negative integer numbers. If the equation has no solution, then μ' is not accessible from μ.

The matrices $\mathbf{D}^{-}$ and $\mathbf{D}^{+}$ for the net from Fig. 5 have the form:

$$\mathbf{D}^{-} = \begin{bmatrix} 1&1&1&0&0&0&0&0 \\ 1&1&0&0&0&0&0&0 \\ 0&1&1&0&0&0&0&0 \\ 0&0&1&0&1&0&0&0 \\ 1&0&0&0&0&1&0&0 \\ 1&0&1&0&0&0&0&0 \\ 0&1&0&0&0&0&1&0 \\ 0&0&0&0&0&0&1&0 \end{bmatrix} \text{ and } \mathbf{D}^{+} = \begin{bmatrix} 0&0&1&0&0&0&0&0 \\ 0&0&0&1&0&0&0&0 \\ 0&0&0&0&1&0&0&0 \\ 0&0&1&0&0&0&0&0 \\ 0&0&1&0&0&1&0&0 \\ 0&0&0&0&0&0&1&0 \\ 0&0&1&0&0&0&0&0 \\ 0&0&0&0&0&0&0&1 \end{bmatrix}. \tag{6}$$

The incident matrix **D** is respectively:

$$\mathbf{D} = \mathbf{D}^{+} - \mathbf{D}^{-} = \begin{bmatrix} 0&0&1&0&0&0&0&0 \\ 0&0&0&1&0&0&0&0 \\ 0&0&0&0&1&0&0&0 \\ 0&0&1&0&0&0&0&0 \\ 0&0&1&0&0&1&0&0 \\ 0&0&0&0&0&0&1&0 \\ 0&0&1&0&0&0&0&0 \\ 0&0&0&0&0&0&0&1 \end{bmatrix} - \begin{bmatrix} 1&1&1&0&0&0&0&0 \\ 1&1&0&0&0&0&0&0 \\ 0&1&1&0&0&0&0&0 \\ 0&0&1&0&1&0&0&0 \\ 1&0&0&0&0&1&0&0 \\ 1&0&1&0&0&0&0&0 \\ 0&1&0&0&0&0&1&0 \\ 0&0&0&0&0&0&1&0 \end{bmatrix} = \begin{bmatrix} -1&-1&-1&1&0&0&0&0 \\ -1&-1&0&0&1&0&0&0 \\ 0&-1&-1&0&0&1&0&0 \\ 0&0&-1&11&0&0&0 \\ -1&0&0&1&0&-1&0&0 \\ -1&0&-1&0&0&0&1&0 \\ 0&-1&0&1&0&0&-1&0 \\ 0&0&0&0&0&0&-1&1 \end{bmatrix} \tag{7}$$

The vector of the next marking is obtained after composing and evaluating the equation (5):

$$[1\ \ 1\ \ 1\ \ 0\ \ 0\ \ 0\ \ 0\ \ 0] + [1\ \ 0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 0] \cdot \begin{bmatrix} -1&-1&-1&1&0&0&0&0 \\ -1&-1&0&0&1&0&0&0 \\ 0&-1&-1&0&0&1&0&0 \\ 0&0&-1&1&-1&0&0&0 \\ -1&0&0&1&0&-1&0&0 \\ -1&0&-1&0&0&0&1&0 \\ 0&-1&0&1&0&0&-1&0 \\ 0&0&0&0&0&0&-1&1 \end{bmatrix} =$$

$$= [1\ \ 1\ \ 1\ \ 0\ \ 0\ \ 0\ \ 0\ \ 0] + [-1\ -1\ -1\ \ 1\ \ 0\ \ 0\ \ 0\ \ 0] = [0\ \ 0\ \ 0\ \ 1\ \ 0\ \ 0\ \ 0\ \ 0].$$

The unity at the fourth place in the obtained vector of marking means that a mark has appeared in position p_4. Taking under consideration the value of the state it is seen that case 4 of the above-mentioned options has been realized. If the positions p_2 and p_3 have been first marked in the initial net, the only possible transitions that could be executed is t_3. In this situation the state of waiting takes place, which is equivalent to the described case 1. The mathematical interpretation is as follows:

$$[0\ 1\ 1\ 0\ 0\ 0\ 0] + [0\ 0\ 1\ 0\ 0\ 0\ 0\ 0] \cdot \begin{bmatrix} -1 & -1 & -1 & 1 & 0 & 0 & 0 & 0 \\ -1 & -1 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & -1 & -1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 1 & -1 & 0 & 0 & 0 \\ -1 & 0 & 0 & 1 & 0 & -1 & 0 & 0 \\ -1 & 0 & -1 & 0 & 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 1 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & 1 \end{bmatrix} =$$

$$[0\ 1\ 1\ 0\ 0\ 0\ 0\ 0] + [0\ {-1}\ {-1}\ 0\ 0\ 1\ 0\ 0] = [0\ 0\ 0\ 0\ 0\ 1\ 0\ 0].$$

After a certain time, if a mark appears in p_1, the only possible transition that could be activated would be t_5. Finally, state p_4 would be marked and the ship would leave the port with the cargo but after a certain delay:

$$[1\ 0\ 0\ 0\ 0\ 1\ 0\ 0] + [0\ 0\ 0\ 0\ 1\ 0\ 0\ 0] \cdot \begin{bmatrix} -1 & -1 & -1 & 1 & 0 & 0 & 0 & 0 \\ -1 & -1 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & -1 & -1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 1 & -1 & 0 & 0 & 0 \\ -1 & 0 & 0 & 1 & 0 & -1 & 0 & 0 \\ -1 & 0 & -1 & 0 & 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 1 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & 1 \end{bmatrix} =$$

$$[1\ 0\ 0\ 0\ 0\ 1\ 0\ 0] + [-1\ 0\ 0\ 1\ 0\ {-1}\ 0\ 0] = [0\ 0\ 0\ 1\ 0\ 0\ 0\ 0\ 0].$$

The situation corresponding to the described Case 2. is presented below by means of the equivalent matrix equations:

$$[1\ 0\ 1\ 0\ 0\ 0\ 0\ 0] + [0\ 0\ 0\ 0\ 0\ 1\ 0\ 0] \cdot \begin{bmatrix} -1 & -1 & -1 & 1 & 0 & 0 & 0 & 0 \\ -1 & -1 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & -1 & -1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 1 & -1 & 0 & 0 & 0 \\ -1 & 0 & 0 & 1 & 0 & -1 & 0 & 0 \\ -1 & 0 & -1 & 0 & 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 1 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & 1 \end{bmatrix} =$$

$$[1\ 0\ 1\ 0\ 0\ 1\ 0\ 0] + [-1\ 0\ {-1}\ 0\ 0\ 0\ 1\ 0] = [0\ 0\ 0\ 0\ 0\ 0\ 0\ 1\ 0].$$

Only transition t_8 can be executed from the obtained marking:

$$[0\ 0\ 0\ 0\ 0\ 0\ 1\ 0] + [0\ 0\ 0\ 0\ 0\ 0\ 0\ 1] \cdot \begin{bmatrix} -1 & -1 & -1 & 1 & 0 & 0 & 0 & 0 \\ -1 & -1 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & -1 & -1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 1 & -1 & 0 & 0 & 0 \\ -1 & 0 & 0 & 1 & 0 & -1 & 0 & 0 \\ -1 & 0 & -1 & 0 & 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 1 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & 1 \end{bmatrix} =$$

$$[0\ 0\ 0\ 0\ 0\ 0\ 1\ 0] + [0\ 0\ 0\ 0\ 0\ 0\ -1\ 1] = [0\ 0\ 0\ 0\ 0\ 0\ 0\ 1].$$

If the ship is in a state of waiting, i.e. position p_7 is marked and at the same time a mark appears in p_2 (the land transport vehicle has brought the cargo), the permitted transitions are two – t_7 and t_8. In this case higher priority should be given to t_7 in order to avoid the conflict situation between the two transitions and to execute transition t_7:

$$[0\ 0\ 0\ 0\ 0\ 0\ 1\ 0] + [0\ 0\ 0\ 0\ 0\ 0\ 1\ 0] \cdot \begin{bmatrix} -1 & -1 & -1 & 1 & 0 & 0 & 0 & 0 \\ -1 & -1 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & -1 & -1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 1 & -1 & 0 & 0 & 0 \\ -1 & 0 & 0 & 1 & 0 & -1 & 0 & 0 \\ -1 & 0 & -1 & 0 & 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 1 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & 1 \end{bmatrix} =$$

$$[0\ 0\ 0\ 0\ 0\ 0\ 1\ 0] + [0\ -1\ 0\ 1\ 0\ 0\ -1\ 0] = [0\ 0\ 0\ 1\ 0\ 0\ 0\ 0].$$

In order to minimize the time for interruption of IMT, it is necessary to dispose of exact and timely information about the movement of the transport vehicles, the total volume of the transferred cargo, the duration of coordinated activities at the port for transferring the cargo and the conditions in the port. Similar data are provided by the information flows connecting and servicing the intermodal transport system. Except for their independent importance for the operative management, these flows exert also substantial impact on the choice of the strategic solution for optimising the control of transport activities.

4. INFORMATION FLOWS AND THEIR MODELLING

The term of an "information flow" should imply the whole set of data used by the system and processed by it for performing the transport node activity. The connection of the information-processing centre with the information source should be multilateral, so that the rhythmic functioning of the transport chain should be ensured. This connection is realized by means of a local computer network situated in the centres for collecting, processing and dissemination of the information (CCPDI). These centres should be located if possible in the ports, which represent the nodes of different load flows and means (vehicles) for their transport.

There are three types of information in the database:

1. **Static data –** the input of data proceeds once and updating is made after a very long period of time. Such data concern information about the ship (vehicle) – name, identification number, load capacity, engine power, fuel, velocity, etc.; data for the hydrometeorological regime of the water (transport) route – dimensions, depth, flow velocity, lock clearance, time for lifting/letting down the ship or time for passing through the lock, height of gates under the bridges, situation of the border check-points, etc.; port characteristics, for the ships; storehouses, internal port transport, norms for reloading of cargoes from storehouse → quay place →ship and vice versa, supply of spare parts, etc.
2. **Dynamic data with longer duration of updating –** these are data for the load type, time for loading the ship and hour of departure, rate stakes, freight cost, time and date of ship arrival at the different points, etc.
3. **Dynamic data with short duration of existence** – coordinates of ship location, hydrometeorological forecast, temporary changes in the water route. The updating of dynamic data is made automatically or manually by the servicing personnel.

The incoming information from the users is subjected to control and is arranged according to urgency and significance for input. Depending on its urgency the input of information proceeds: immediately; according to the order of arrival; in certain moments of the twenty-four-hour period.

The users of information might be: Ship; Navigation company; Ship owner; Load senders; Shipping agency; Load recipient; Port; Inspection on navigation; Marine police; Customs office; Ecological organization; Rescue-coordination centre; Border checkpoint; Railroad centre; Motor transport centre; Others.

5. DATA EXCHANGED BETWEEN THE SHIP AND THE INFORMATION CENTRE

All types of data can be presented by Petri's nets, in which the transitions represent the transfer (transmitting) action itself and the states indicate which data have already been transmitted.

– Data transmitted from the ship: Place of the ship; Velocity of movement; Time of arrival in a port; Manner of load distribution; Order of unloading; Possibility for additional loading; Necessity of replenishing the reserves – fuel, water, food, spare parts; Necessity of repair; Necessity of new certification of the technical equipment of the ship; Necessity of medical help; Others.

– Data transmitted by the system to the ship: Order in the port / quay place; Time of taking stand at the quay place; Manner and sequence of replenishing the reserves; Possibilities for making a repair, stages of repair works; Stages of releasing / accepting the load; Duration of loading-unloading activities; Duration of the repair.

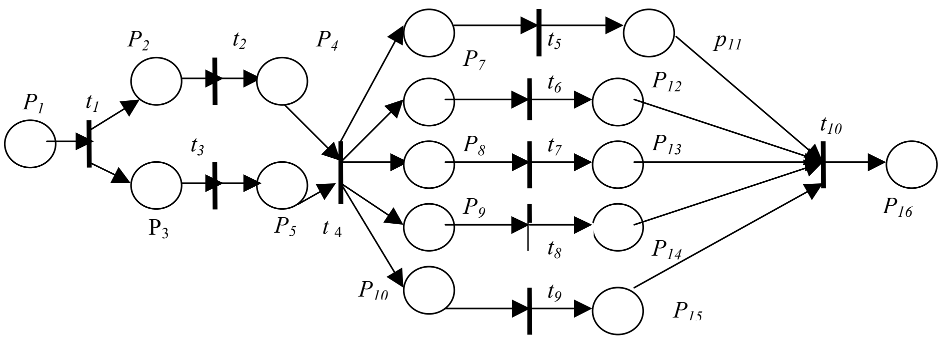


Fig. 6. A net corresponding to data transmitted from the ship

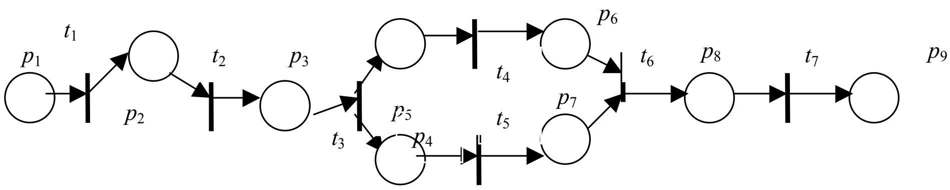


Fig. 7. A net corresponding to data transmitted from the system to the ship

The land transport vehicle transmits data for: Location of the transport vehicle; Velocity of movement; Supposed time of arrival in a port; Manner of load distribution; Order of unloading; Possibility for additional loading; Necessity of replenishing the reserves – fuel, spare parts; Necessity of repair.

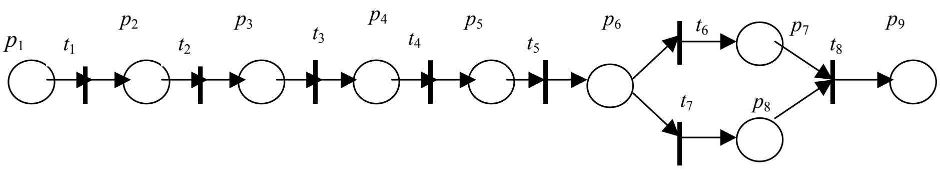


Fig. 8. A net corresponding to data transmitted from the land transport vehicle

The land transport vehicle receives data about: Order in the port or quay place; Time for taking stand at the quay place or in front of the storehouse; Stages of releasing / accepting the load; Duration of loading-unloading activities; Duration of the repair.

Λ The owners of the transport vehicles or their representatives submit data for: Readiness for transportation of a given load; Confirmation of freight cost; Time for submitting the ship (transport vehicle) to receive a load; Readiness of the ship for leaving the port; Requirements for replenishing the reserves of the ship; Repair; Others.

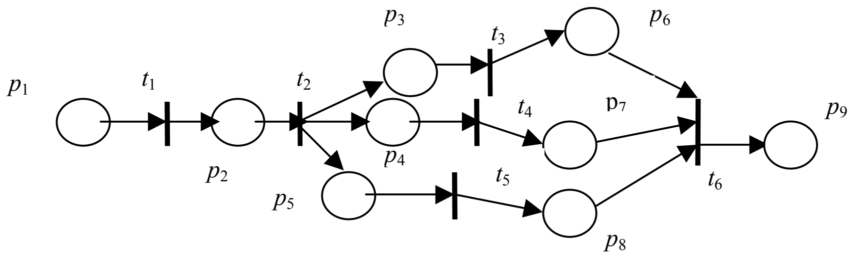


Fig. 9. A net corresponding to data transmitted from the owners of transport vehicles

Λ The owners of the transport vehicles receive data for: Time for taking stand at the quay place or in front of the storehouse; Term for unloading; Harbour taxes; Acceptance through border checkpoint (BCP); Condition of the water (land) route; Restrictions of movement – control checking; Hydrometeorological conditions; In cases of accident – state of the transport vehicle; Overloading of different sections; Information about accidents along the route; Information about the load – type, quantity, load sender, load recipient, etc; Others.

1 The load senders and shipping agencies transmit data to the system about: Load – type, amount, packing; Way of transportation; Term for delivering the load in a particular port; Way of payment.

1 The load senders and shipping agencies receive data about: Ship for transporting the load; Freight cost; Way of payment; Time for carrying out the reloading operations; Time for leaving the port and transportation to the particular port; Term for carrying out the unloading operations; Transportation of the load from the quay to the load recipient; Others.

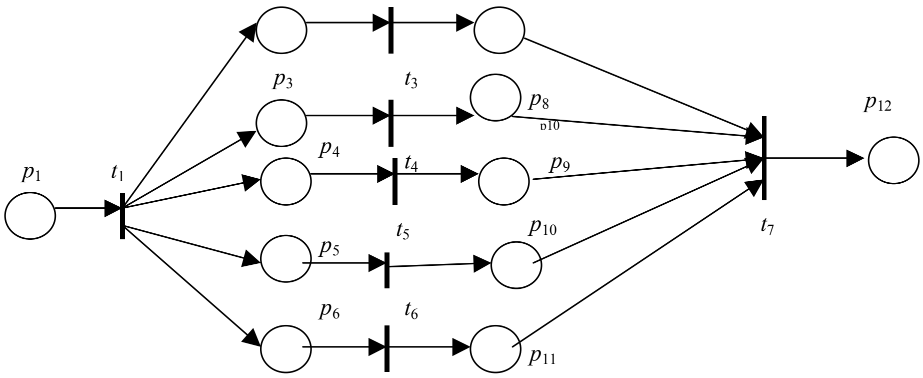


Fig. 10. A net corresponding to data transmitted from the system to the load senders and shipping agencies

The port transmits information to the system about: Quay places – situation, dimensions, depth; Port equipment for carrying out the reloading operations at each quay – stationary and mobile; Access roads to the quays for the motor and railway transport; Specialization of the quays for reloading certain cargoes, especially hazardous cargoes;

Norms for reloading; Harbour taxes; Taxes for loading and unloading activities; Possibilities for supply of water, fuel-grease materials, food, electric supply, etc.; Weighing (measuring) the cargo; Duration of the loading-unloading operations; Possibilities for performing loading-unloading operations in one or more places on the ship. The port receives information about: Arriving loads – type, quantity, allocation, packing; Type of transport delivering the loads; Possibilities for storage and special requirements; Certificate of the load from the customs office; Time of ship arrival; Specific conditions during the stay of the ship; Freight cost; State of the loading rooms; Type of the loading rooms.

6. CONCLUSIONS

The method described above has show important tools for modeling of information flows and different interactions in the intermodal transport.

Future development is envisaged related to the complex control system in a port.

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PRIMENA PETRI MREŽA ZA MODELOVANJE TRANSPORTNIH TOKOVA

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Petri mreže su jedan od mogućih koncepata za modelovanje transportnih tokova. Pokazuje se da je ovaj pristup veoma pogodan iz sledećih razloga: Petri mreže su zasnovane na uzročno-posledičnim vezama koje često srećemo u transportnim problemima, a grafički prikaz elemenata mreže se lako prepoznaje od strane projektanata, što znači da se transportni problem lako realizuje. U radu su dati primeri modelovanja transportnih problema.