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The Simulation Model as a Tool for Diagnostics of Operation Equipment

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Abstract

Efficiency of handling equipment reduces the service time of vehicles arriving at the container terminal. A simulation model of the operation of handling equipment allows to reduce, the time for diagnosis handling technique with its failure. The model is constructed by means of apparatus of Petri nets the formalism of Petri nets provides the precision of definitions and reflects the structural and logical connection of the simulated events. The visualization and simplicity of Petri nets allows the technician has no special training to use these models. This paper examines the reachstacker model, these types of machines that are used in container terminals. A Petri net simulating the operation of the reachstacker – hierarchical, has a built-in network positions. Hierarchy of networks identified position to ensure secure operation techniques, conflict situation, analyzed solutions. Position having the chips are nodes, which can cause failures.

Keywords: simulation model, handling equipment, diagnosis, Petri net, nested nets

1. Introduction

One of the widespread types of the handling equipment (HE) used on container terminals are reachstacker (*RS*). Structural RS model regardless of his model has the form

$$RS = \{EN, HS, ES, HT, SP\}, \quad (1)$$

where EN – engine, HS – hydraulic system, ES – electric system, SP – spreader, HT – hydraulic transmission.

The aggregates constituting of RS which are specified in model (1) can be considered as the independent systems having the input and output parameters which are exposed to diagnosis. Diagnosis generally establishes the fact that the machine is operable or inoperable. Technical condition of *RS* (TC_{RS}) is described by the functional model:

$$TC_{RS} = \begin{cases} 1, & if \quad HE \quad is \quad operable; \\ 0, & if \quad HE \quad is \quad inoperable. \end{cases} \quad (2)$$

For restoring of functionality it is necessary to establish what knot or aggregate of the machine was broken, so that to make his replacement or repair. Modern equipment is equipped with onboard computers that identify failures. Information is read out from the onboard computer in case of connection of laptop to it with the necessary software. Organizations which are dealers of the producer of HE have such programs. Repair services on the terminals don't have such program, diagnosis is carried out by the experts having experience of HE exploitation. The model with imitation of work of the HE main nodes is developed for effective diagnosing of HE. At the model research it is necessary to consider what consequences nodes failures render on a system or HE in general.

The simulation model of HE work constructed using Petri nets is presented in fig. 1 [1, 2]. This Petri net is complex hierarchical network [3] where each position, except p_{10} position, has his own nested net [4].

The principles of modularity and structural similarity are used at the creation of hierarchical Petri net. Using the principle of a modularity, system (in our case it is RS) is divided into separate aggregates which in case of failure can be replaced on serviceable, and the inoperable aggregate will be sent to repair (when using a method of aggregate repair). The knot or the mechanism performing the specified function is called the aggregate. In our work each aggregate has the simulation model constructed using Petri nets. The model structure corresponds to the structure of the modelled object which is called reachstacker.

2 Analysis of Algorithms

Analyzing the network functioning presented in fig. 1 one may say, that the network has only one conflict situation in p_8 position.

The electrical system provides functioning of the onboard network and charging of the storage battery (SB). At the electric system failure the onboard network can operated by the storage battery. If there is no charging of the storage battery, then in case of failure of the generator, the reachstacker work will be stopped.

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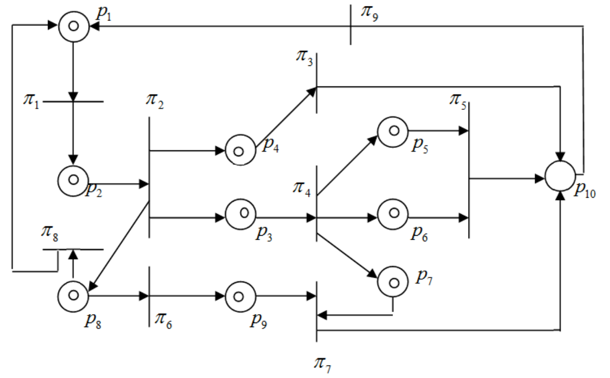


Fig. 1. Algorithm of reachstacker work:p_1 – start-up system of the engine; p_2 – engine; p_3 – hydraulic system; p_4 – hydraulic transmission; p_5 – cylinders of arrow lifting; p_6 – cylinder of arrow extension; p_7 – hydraulic system of spreader; p_8 – electric system of the reachstacker; p_9 – electric system of the spreader; p_{10} – loader in operating state; π_1 – triggering of the start-up system; π_2 – engine idling; π_3 – hydraulic transmission in work; π_4 – hydraulic installation in work; π_5 – lifting and extension of an arrow in work; π_6 – electric system in work; π_7 – spreader in work; π_8 – charging of the storage battery; π_9 – machine stop.

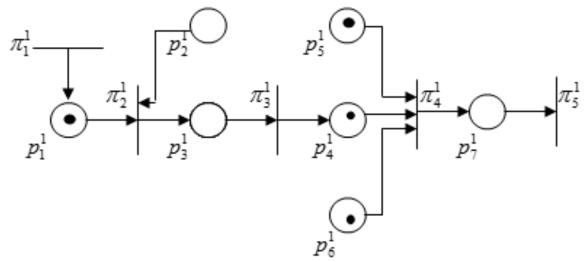


Fig. 2:. Integrated Petri net of p_1 position: p_1^1 – storage battery; p_2^1– mass key; p_3^1– ignition key; p_4^1 – block of safety locks; $p_5^{\ 1}$– start-up blocking (the gear shift knob isn't set); p_6^1 – the button of an emergency stop of the engine is switched on; p_7^1– starter; π_1^1– charging of the storage battery; π_2^1– the electrical circuit is closed on the body (the mass is switched on); π_3^1– turn of the ignition key; π_4^1 – the electrical circuit is closed; π_5^1 – triggering of the retractor relay of starter, the gearwheel of the starter engages.

At triggering of the start-up system (p_1), the engine (p$_2$) is started and idles. The engine is connected to hydraulic system (p_3) and hydraulic transmission (p_4). If gear is engaged transmission begins to work, setting the reachstacker in motion. The hydraulic system (p_3) while working depending on the input signal provides operation of the cylinders of arrow lifting (p_5), the cylinder of arrow extension (p_6) and hydraulic system of spreader (p_7).

The reachstacker work is considered without real time only from positions of cause and effect relationships, and the functional model is considered as conveyor system [3, 5]. A task of simulation model is check of the modelled process. In the conveyor system start of new operation can't be allowed if the previous operation isn't complete [7-9]. This property is important at diagnosing of the system work. Having carried out decomposition of the machine, it is possible to define why this or that knot doesn't work.

The integrated Petri net of p_1 position (fig. 2) imitates work of the start-up system of *RS*. At triggering of the nested net of p_1 position the chip moves to transition π_1, the gearwheel of starter engages with flywheel of the engine and transfers to him rotation. Engine start-up will be carried out after triggering of the nested net of p_2 position. Supply from the storage battery after switching-on of mass key (p_2^1) is transferred on the chain to the ignition lock (p_3^1).

At turn of the ignition key (π_3^1) if the chips from the p_4^1, p_5^1, p_6^1 positions have come to transition π_4^1, the π_4^1 transition will switch on, supply arrives on the starter terminals (p_7^1), the retractor relay is triggered, the gearwheel engages. The p_5^1 position can block the engine start-up if the gearshift knob won't be set in neutral position.

The starter gearwheel (p_7^1) untwists the engine flywheel (Fig. 3). At rotation of the flywheel π_1^2 the movement is transferred to the fuel priming pump (p_2^2) from which fuel is fed into the high-pressure fuel pump[1], p_2^2 position, whence fuel is fed on nozzle (p_2^2). For the fuel supply to the fuel priming pump, the signal must be supplied to the electromagnetic valve. In the absence of a signal the π_5^2 transition won't be switched on, opening of the valve won't happen. For triggering of the transition the following conditions have to be satisfied: fuel existence (p_8^2), the electromagnetic valve (p_6^2) has to be repaired, the signal has to come from the ignition system (p_7^2).

For the engine operation it is necessary that conditions which are designated in p_{10}^2, p_{11}^2, p_{12}^2, p_{13}^2 positions by the chips have been complied. If from one of these positions the chip doesn't come on π_8^2 transition the engine won't be started.

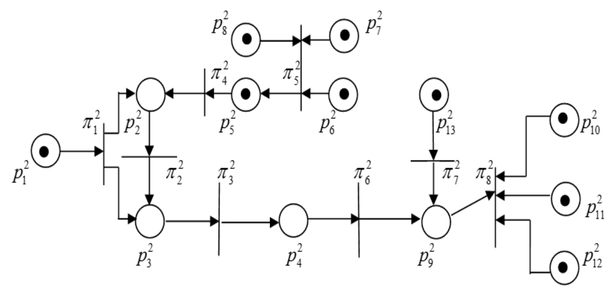


Fig. 3. Integrated Petri net of p_2 position:p_1^2 – the engine flywheel; p_2^2 – the fuel priming pump; p_3^2 – the high-pressure fuel pump; p_4^2 – nozzle; p_5^2 – fuel in the system; p_6^2– the electromagnetic valve of the fuel priming pump is repaired; p_7^2 – signal from the ignition key; p_8^2 – fuel existence; p_9^2 – fuel air mixture in the cylinder; p_{10}^2 – the sizes of cylinder and piston group within predetermined limits; p_{11}^2 – the angles of gas distribution correspond to technical documentation; p_{12}^2 – pressure in oil system corresponds to technical documentation; p_{13}^2 – the turbocompressor is corrected; π_1^2– flywheel rotation; π_2^2– fuel supply to the high-pressure fuel pump; π_3^2 – fuel supply to the nozzle; π_4^2 – fuel supply to the fuel priming pump; π_5^2 – triggering of the electromagnetic valve of the fuel priming pump; π_6^2 – fuel injection to the cylinder; π_7^2 – air boost into the cylinder; π_8^2 – engine increases turns *XX*.

The hydraulic system (p_3) and hydraulic transmission (p_4) are ready to work after the engine start-up (p_2).

The model of hydraulic system is presented in fig. 4. The engine through the system of gearwheels transfers rotation to the hydraulic pumps (positions: p_2^3, p_3^3 и p_8^3)[2]. Pumps has feedback with the engine, engine turns decrease at reduction of pressure in hydraulic system. All pumps has chips it identifies their efficiency. Upon transition of one of the

[1] On the latest reachstacker models there are fuel systems which are equipped the pump nozzles.

[2] Depending on the model and the producer of the reachstacker, pumps of other productivity can be established.

pumps to a disabled state the transitions π_3^3, π_7^3 won't work, it blocks operation of hydraulic distributors (positions: p_4^3, p_9^3) and, therefore, all hydraulic system. Positions p_4^3, p_9^3 are conflictual, the control of hydraulic distributors is carried out by signal fed on the electromagnetic valve, depending on need of supply of hydraulic liquid in this or that executive body. Position p_{13}^3 is a discharge; chip having got to this position remains there.

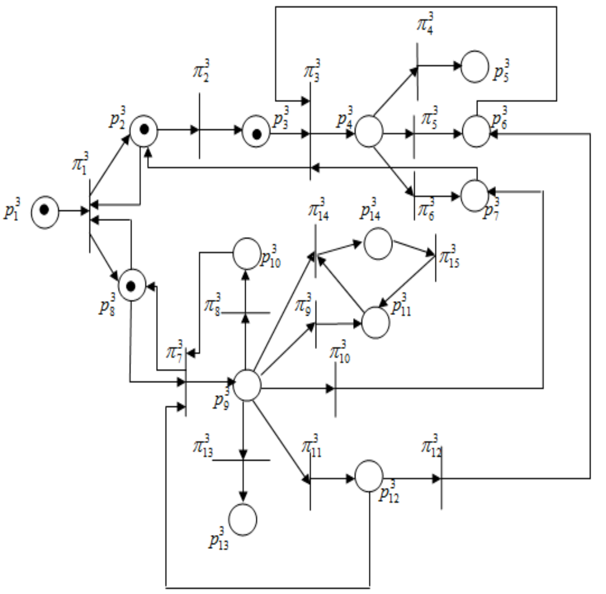


Fig. 4. Integrated Petri net of p_3 position:p_1^3 – engine; p_2^3 – the pump with a productivity of 100 cm^3/min (coupled); p_3^3 –pump (attached implement) with a productivity of 38 cm^3/min; p_4^3 – hydraulic distributor (right); p_5^3 – hydraulic system of spreader; p_6^3 – hydraulic distriburtor of the right lifting cylinder; p_7^3 – hydraulic distriburtor of the cylinder of the arrow extension; p_8^3 – the pump with a productivity of 100 cm^3/min; p_9^3 – hydraulic distributor (left); p_{10}^3 – steering machine (orbitrol); p_{11}^3 – hydroaccumulator; p_{12}^3 – hydraulic distriburtor of the left lifting cylinder; p_{13}^3 – parking brake; p_{14}^3 – braking pressure; π_1^3 – drive of the pumps in motion; π_2^3 – rotation transfer to the attached implement pump; π_3^3– increase/decrease in feed of the pump; π_4^3– triggering of the electromagnetic control valve of the spreader hydraulic system; π_5^3 – triggering of the electromagnetic valve of the right cylinder of lifting arrow; π_6^3 – triggering of the electromagnetic control valve of the cylinder of the arrow extension; π_7^3 – increase/decrease in feed of the pump; π_8^3 – valve opening of the steering machine (orbitrol); π_9^3 – valve triggering of the hydroaccumulator recharge; π_{10}^3 – triggering of the electromagnetic control valve of the cylinder of the arrow extension; π_{11}^3 – triggering of the electromagnetic valve of the left cylinder of lifting arrow; π_{12}^3 – equalizing of pressure in the lifting cylinders; π_{13}^3 – turning on of the parking brake; π_{14}^3 – pressure control in the hydraulic system; π_{15}^3 – valve opening of the hydroaccumulator.

Operation of the hydraulic transmission (torque converter) is presented in Fig. 5. The hydraulic transmission is intended for transfer of mechanical power of the engine through the crankshaft to the driving axle.

Rotation from the engine is transferred (transition π_1^4) to the torque converter (p_2^4) which is idling (π_1^4). Depending on the control knob position (p_7^4) the signal is supplied to one of the transitions π_3^4 or π_4^4. The position p_7^4 is conflictual, the conflict resolutions is carried out by external influence (by the operator of the machine) depending on a situation.

Integrated Petri net of p_5 position (the operation of hydraulic cylinders of lifting) is considered in fig. 6. The model shows that the net has two conflictual positions: p_3^5 and p_4^5. The conflict in a position p_3^5 is solved by means of situational management [8, 10] and has its own the network (fig. 6a) which includes identification of efficiency of piston seals of hydraulic cylinder.

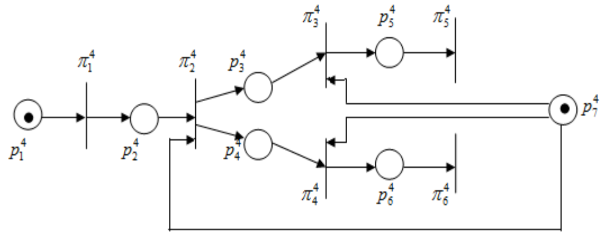


Fig. 5. Integrated Petri net of p_4 position: p_1^4 – engine; p_2^4 – torque converter; p_3^4 – *electromagnetic valve* of forward stroke; p_4^4 – *electromagnetic valve* of back stroke; p_5^4 – valve of forward stroke is opened; p_6^4 – valve of back stroke is opened; p_7^4 – the control knob; π_1^4 – rotation transfer from the engine; π_2^4 – torque converter operation at idle; π_3^4 – triggering of the *electromagnetic valve* of forward stroke; π_4^4 – triggering of the *electromagnetic valve* of back stroke; π_5^4 – crankshaft rotation in a clockwise direction (forward motion); π_6^4 – crankshaft rotation counterclockwise (backward movement).

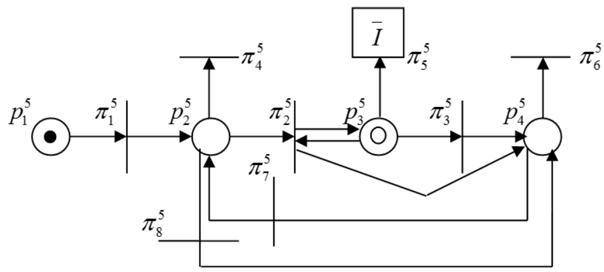


Fig. 6. Integrated Petri net of p_5 position: p_1^5 – oil pressure in the hydraulic distributor; p_2^5 – subpiston cavity of the cylinder; p_3^5 – piston sealing; p_4^5 – over piston cavity of the cylinder; π_1^5 – valve opening; π_2^5 – pressure increasing in the subpiston cavity; π_3^5 – pressure increasing in the over piston cavity; π_4^5, π_6^5 – opening of the drain valve; π_5^5 – extension of rod of the hydraulic cylinder; π_7^5, π_8^5 – opening of bypass valves.

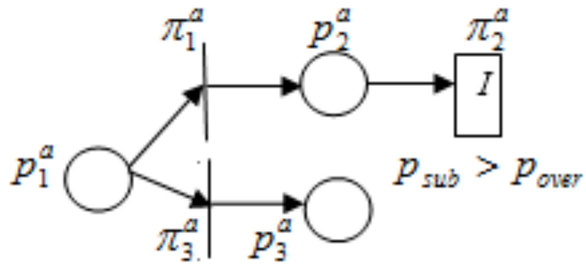


Fig. 6 a. Integrated Petri net of p_3^5 position:p_1^a – seals are serviceable; p_2^a – seals are efficient; p_3^a – seals are inefficient; π_1^a – pressure increasing in the subpiston cavity; π_2^a – extension of rod of the hydraulic cylinder; π_3^a – restart-up of hydraulic liquid in the over piston cavity.

The rod of the hydraulic cylinder begins to move (transition π_2^a), only if the seals are in good working condition. Transition π_2^a has protection, according terminology [4]. The label $\bar{I}$ is located in transition π_5^5. In the integrated net of position p_3^5 the transition π_2^a has the lable *I*. At coincidence of these labels which are mutually complementary and synchronize the initiation of transitions

[3,11], the transition π_5^5 is initiated. For coincidence of the lables the transition π_2^a has protection: $p_{sub} > p_{over}$[3]. If the labels do not match, then the transition π_5^5 is initiated.

Position p_3^5 (fig. 6) is conflictual. If the seals are not operable the transition π_5^5 won't work, the transition π_2^5 will turn on and hydraulic liquid will come to the over cavity (position p_4^5), extension of the rod of the hydraulic cylinder won't occur.

Operation model of the hydraulic cylinder of arrow extension is presented in fig. 7. The model has two conflictual situations: in positions p_1^6 and p_4^6. In the first case the situation is resolved by the machine operator depending on what position needs to be given to the arrow. The position p_1^6 has a chip which shows that the joystick is in operating state. In the second case the conflict is resolved depending on what signal was received. Integrated net of p_4^6 position is presented in fig. 7 a. In a position p_1^{6a} there is a chip which shows that in system there is pressure of hydraulic liquid. Depending on the received signal the transition π_1^{6a} or π_2^{6a} will work. Both transitions have protection $p_{sys} \geq p_{set}$[4]. If the condition of protection is satisfied that transitions with identical indexes (*x* or *y*) will work. If pressure in system less set pressure, then the chip passes from position p_1^{6a} into position p_2^{6a}. In this case any of transitions (π_3^6, π_4^6) won't work, the movement of hydraulic cylinder won't occur. In position p_8^6 there is a conflict situation which is resolved depending on a situation, if there is the arrow extension or the arrow assembly

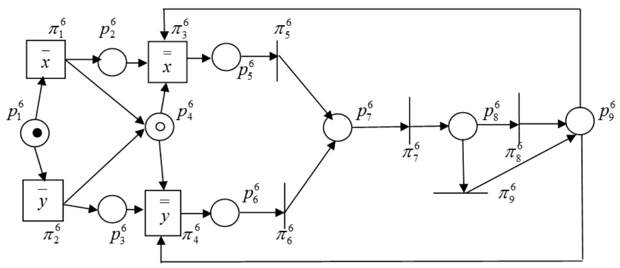
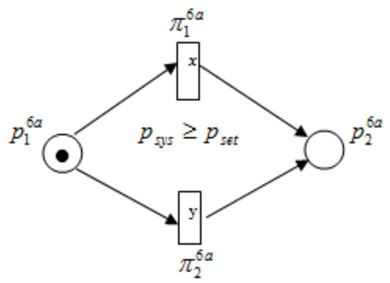


Fig. 7. Integrated Petri net of p_6 position: p_1^6 – joystick; p_2^6 – *electromagnetic valve* of the arrow extension; p_3^6 – *electromagnetic valve* of the arrow assembly; p_4^6 – oil pressure in the hydraulic distributor; p_5^6 – subpiston cavity of cylinder; p_6^6 – over piston cavity of cylinder; p_7^6 – piston seals; p_8^6 – control sensor of arrow sortie; p_9^6 – blocking of movement of the piston rod; π_1^6 – signal on the arrow extension; π_2^6 – signal on the arrow assembly; π_3^6, π_4^6 – opening / closing of the valve; π_5^6 – pressure increasing of the subpiston cavity; π_6^6 – pressure increasing of the over piston cavity; π_7^6 – cylinder rod movement; π_8^6 – triggering of the sensor of the maximum sortie; π_9^6 – triggering of the sensor of the minimum sortie.



[3] p_{sub} – pressure in the subpiston cavity, p_{over} – pressure in the over piston cavity

[4] p_{sys} – pressure in the hydraulic system, p_{set} – the set pressure in the over piston cavity

Fig. 7a. Integrated net of p_4^6 position: p_1^{6a} – pressure in the hydraulic distributor; p_2^{6a} – pressure in the hydraulic distributor is absent; π_1^{6a} – supply of pressure into the subpiston cavity of the hydraulic cylinder: π_2^{6a} – supply of pressure into the over piston cavity of the hydraulic cylinder.

The model of functioning of hydraulic system of spreader (position p_7, fig. 1) is shown in fig. 8. The position p_1^7 has chip which shows presence of pressure of working liquid. In the absence of chip in position p_1^7 (pressure of working liquid) the model won't work. Working liquid under pressure (p_1^7) is supplied to electromagnetic valves (positions p_2^7, p_3^7, p_4^7, p_5^7). Depending on signal feeding by operator (position p_7^7) the corresponding transition is triggered (π_2^7, π_3^7, π_4^7). Transition π_5^7 will trigger in the presence of chip which has a value of 4 (by the number of induction sensors and indicates that sensors are operable) in positions p_6^7. The chip in this position will be only if there is a turning on of all sensors, the scheme is collected (position p_{12}^7) and the spreader is ready to work (fig. 9). After electromagnetic valve the hydraulic fluid is supplied to the actuating mechanisms (hydraulic cylinders) of positions p_8^7, p_9^7, p_{10}^7, p_{11}^7. After fade in/out load handling bayonets from the container fittings the transition π_{12}^7 is triggered which has a time delay set on time relay of control unit of the spreader. Further the signal of readiness for performance of work is supplied (position p_{17}^7).

In this model, there is a conflict situation - the position p_7^7, the conflict is solved by the operator depending on the need for an overload of 20 or 40 foot container.

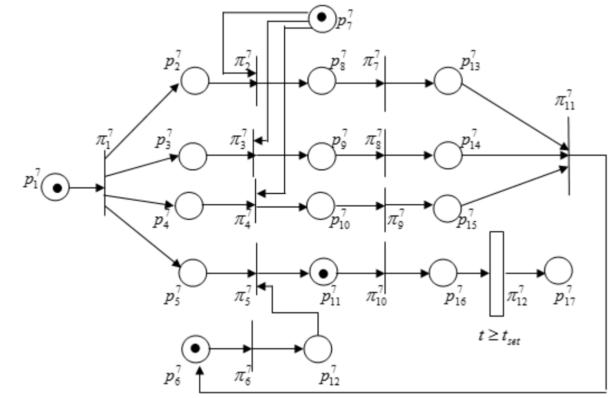


Fig. 8. Integrated Petri net of p_7 position: p_1^7 – oil pressure in the hydraulic system; p_2^7 – electromagnetic valve of cylinders of spreader extension/shift; p_3^7 – electromagnetic valve of cylinders of the spreader moving (positioning); p_4^7 – electromagnetic valve of the hydraulic motor of the spreader rotation; p_5^7 – *electromagnetic valve* of cylinders of opening/closing of load handling bayonets; p_6^7 – induction sensors; p_7^7 – joystick; p_8^7 – hydraulic oil pressure in the cylinders of spreader extension/shift; p_9^7 – hydraulic oil pressure in the cylinder of the spreader moving; p_{10}^7 – hydraulic oil pressure in the hydraulic motor; p_{11}^7 – hydraulic oil pressure in the cylinder of opening/closing of load handling bayonets; p_{12}^7 – assembled electroscheme; p_{13}^7 – spreader feet are moved apart/assembled; p_{14}^7 – spreader in the set position relative to the horizontal; p_{15}^7 – spreader in the set position relative to the vertical; p_{16}^7 – bayonets are closed/opened; p_{17}^7 – signal of spreader readiness to work; π_1^7 – supply of pressure of hydraulic fluid to the spreader hydraulic system; π_2^7 – triggering of *electromagnetic valve* of cylinders of spreader extension/shift; π_3^7 – triggering of *electromagnetic valve* of the spreader moving; π_4^7 – triggering of *electromagnetic valve* of the hydraulic motor of the spreader rotation; π_5^7 – triggering of *electromagnetic valve* of cylinders of opening/closing of load handling bayonets; π_6^7 – short circuit of an electrochain; π_7^7 – extension/shift of the spreader feet; π_8^7 – the spreader moving (positioning); π_9^7 – the

spreader rotation; π_{10}^{7} – rotation of load handling bayonets; π_{11}^{7} – input / output of the spreader from fittings; π_{12}^{7} – triggering of time relay.

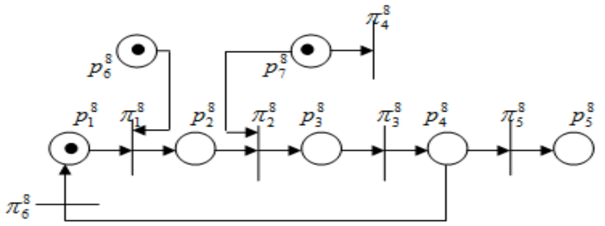


Fig. 9. Integrated Petri net of p_8 position: p_1^8 – *storage battery*; p_2^8 – ignition lock; p_3^8 – starter; p_4^8 – generator; p_5^8 – block of safety locks; p_6^8 – mass key; p_7^8 – emergency stop; π_1^8 – switching on of mass key; π_2^8 – switching on of ignition key; π_3^8 – start-up of engine; π_4^8 – triggering of emergency stop; π_5^8 – food of onboard network; π_6^8 – charge of *storage battery*.

Integrated net of p_8 position (electrical system of the reachstacker) is presented in fig. 9. In this model the position p_1^8, p_6^8, p_7^8 have the chips imitating operating state of a position. Transition π_1^8 will work if two chips from positions p_1^8, p_6^8 come to it. Position p_7^8 is conflictual. If the button of emergency stop isn't switched on, the chip will initiate the transition π_2^8, otherwise, the chip will go to the transition π_4^8 which is deadlock (the machine will stop).

Integrated net of p_9 position (electrical system of the spreader) is presented in fig. 10. In the positions p_1^9, p_2^9, p_3^9, p_4^9 the chips show that the inductive sensor is in a serviceable condition. At failure of one of the sensors the scheme won't be collected and further the transition π_8^9 won't be initiated, the spreader will be in a non-working state.

3. The Solution of the Optimization Problem

Chips from the transitions π_6^9, π_7^9, π_8^9, π_{10}^9come to positions p_9^9. In the position p_9^9 there is a conflict situation which is solved by means of situational management [12-14] and has its own network (fig. 10a). Complexity of this network is that it is conveyor system [4,6,15], and during her work it is necessary observance of the functioning rules. The mathematical apparatus or orgraf with search of Hamilton ways is applied to the solution of tasks of this kind [9-15]. In our work for the solution of this task we use the apparatus of inhibitory Petri nets [1,7]. The inhibitory net is a network where the inhibitory arches forbidding the triggering of transition are possible. If in the entrance position connected with transition by an inhibitory arch there is a label, then this transition won't work.

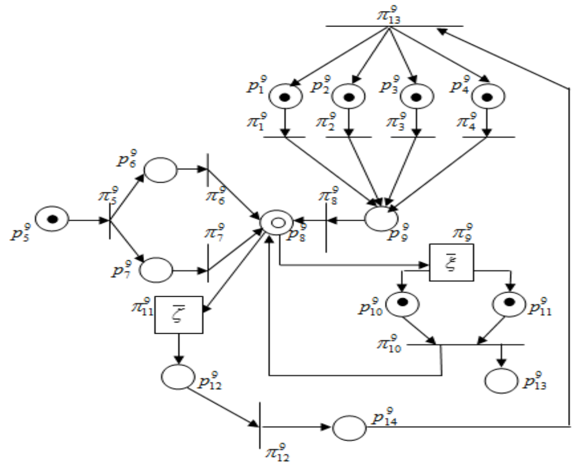


Fig. 10. Integrated Petri net of p_9 position: p_1^9, p_2^9, p_3^9, p_4^9 – inductive sensor; p_5^9 – joystick; p_6^9 – block of bayonets closing; p_7^9 – block of bayonets opening; p_8^9 – control block; p_9^9 – assembled scheme; p_{10}^9 – spreader is engaging / free; p_{11}^9 – alarm board; p_{10}^9 – sensor of fittings opening; p_{11}^9 – sensor of fittings closing; p_{12}^9 – spreader is engaging / free; p_{13}^9 – alarm board; p_{14}^9 – cargo operations are completed; π_1^9, π_2^9, π_3^9, π_4^9 – triggering of the inductive sensor; π_5^9 – signal feeding from the joystick; π_6^9 – signal feeding on the bayonets closing; π_7^9 – signal feeding on the bayonets opening; π_8^9 – signal feeding into the control block; π_9^9 – bayonets rotation; π_{10}^9 – signal transferring on the control block, π_{11}^9 – unblocking of signal feeding on the *electromagnetic valve*; π_{12}^9 – execution of cargo operations; π_{13}^9 – spreader positioning in a starting position.

4 signals come to the position p_8^9. In the integrated net in the position p_1^{9a} (fig. 10a) the chip will have dimension 4. The transition π_1^{9a} won't be started as his start requires 4 chips, and transition is blocked by an inhibitory arch. The chip which is necessary for his start will launch the transition π_3^{9a} which will block electromagnetic valve of the hydraulic system of the spreader.

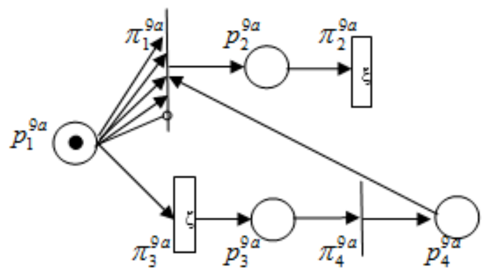


Fig. 10 a. Integrated net of p_8^9 position: p_1^{9a} – sum signal; p_2^{9a} – signal of bayonets opening/closing; p_3^{9a} – signal to the lock / unlock of the *electromagnetic valve*; p_4^{9a} – turn of bayonets is permitted; π_1^{9a} – signal feeding to the bayonets opening/closing; π_2^{9a} – signal transfer on the *electromagnetic valve*; π_3^{9a} – signal transfer on unblocking of the *electromagnetic valve*; π_4^{9a} – delay for a set time.

When the chip gets to the position p_3^{9a}, the signal is supplied on the transition π_1^{9a}, after its triggering, the signal on turn of the bayonets comes. The transitions π_2^{9a} and π_9^9 have labels ξ и $\overline{\xi}$, respectively, and at the coincidence of these labels the transitions will work. The transitions π_3^{9a} and π_{11}^9 also have labels ζ and $\overline{\zeta}$, respectively, and at the coincidence of these labels the transitions will work.

4. Conclusion

Let us analyze the basic Petri net (fig. 1). Liveliness, safety, boundedness, keeping are the main properties of Petri net. The net is live, because basic network and integrated networks are alive [5,7], but not safe. Liveliness of network shows a possibility of triggering of any transition at functioning of the modelled object.

As the network isn't safe, it is limited. The network is persisting and achievable because there is a possibility of network transition from one set state in another.

Positions in which there are integrated nets are knots where there is a probability of failure. At failure of one knot [12, 14], the machine is taken out of service. Using hierarchy of networks, it is possible to make deeper consideration of functioning of any knot. Such model is suitable for development of the computer programs modeling of object functioning.

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