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

$$RS = \{EN, HS, ES, HT, SP\},$$


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:

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

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 $p_{9}$ 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 be stopped. If there is no charging of the storage battery, then in case of failure of the generator, the reachstacker work will be stopped.
possible to define why this or that knot does
Having carried out decomposition of the machine, it is
property is i
only from positions of cause and effect relationships, and the
the cylinders of arrow lifting (π5)

Fig. 1. Algorithm of reachstacker work: p1 – start-up system of the
engine; p2 – engine; p3 – hydraulic system; p4 – hydraulic transmission;
p5 – cylinders of arrow lifting; p6 – cylinder of arrow extension; p7 –
hydraulic system of spreader; p8 – electric system of the reachstacker; p9 –
electric system of the spreader; p10 – loader in operating state; π1 –
triggering of the start-up system; π2 – engine idling; π3 – hydraulic
transmission in work; π4 – hydraulic installation in work; π5 – lifting and
extension of an arrow in work; π6 – electric system in work; π7 –
spreaders in work; π8 – extension of an arrow in work; π9 –
triggering of the engine; π10 – engine.

The integrated Petri net of p1 position: p1 – storage battery; p2 –
mass key; p3 – ignition key; p4 – block of safety locks; p5 – start-up
blocking (the gear shift knob isn’t set); p6 – the button of an emergency
stop of the engine (position of which is determined limits); p7 – the electrical circuit is closed on the body (the
mass is switched on); π1 – turn of the ignition key; π2 – the electrical circuit is
closed; π3 – triggering of the retractor relay of starter, the gearwheel
of the starter engages.

At triggering of the start-up system (p1), the engine (p2)
is started and idles. The engine is connected to hydraulic
system (p3) and hydraulic transmission (p4). If gear is
engaged transmission begins to work, setting the
reachstacker in motion. The hydraulic system (p3) while
working depending on the input signal provides operation of the

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 p1 position (fig. 2) imitates
work of the start-up system of RS. At triggering of the nested
net of p1 position the chip moves to transition π1, 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 p2 position. Supply from
the storage battery after switching-on of mass key (p2) is
transferred on the chain to the ignition lock (p5).

At turn of the ignition key (π1) if the chips from the p4, p5,
p6 positions have come to transition π1, the π2 transition will switch on, supply arrives on the starter
terminals (p5), the retractor relay is triggered, the gearwheel
engages. The p5 position can block the engine start-up if the
gearshift knob won’t be set in neutral position.

The starter gearwheel (p2) untwists the engine flywheel
(Fig. 3). At rotation of the flywheel π1 the movement is
transferred to the fuel priming pump (p5) from which fuel is
fed into the high-pressure fuel pump (p6), whence fuel
is fed on nozzle (p3). 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 π7
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 (p23), the
electromagnetic valve (p3) has to be repaired, the signal has
to come from the ignition system (p11).

For the engine operation it is necessary that conditions
which are designated in p11, p12, p13, p14 positions by the
chips have been compiled. If from one of these positions the
chip doesn’t come on π7 transition the engine won’t be
started.

Fig. 2. Integrated Petri net of p1 position: p1 – storage battery; p2 –
mass key; p3 – ignition key; p4 – block of safety locks; p5 – start-up
blocking (the gear shift knob isn’t set); p6 – the button of an emergency
stop of the engine (position of which is determined limits); p7 – the electrical circuit is closed on the body (the
mass is switched on); π1 – turn of the ignition key; π2 – the electrical circuit is
closed; π3 – triggering of the retractor relay of starter, the gearwheel
of the starter engages.

The hydraulic system (p3) and hydraulic transmission
(p4) are ready to work after the engine start-up (p2).

The model of hydraulic system is presented in fig. 4. The
equipment of the pump nozzles. The
hydraulic system (p23) pumps
has feedback with the engine, engine turns decrease at reduction
of pressure in hydraulic system. All pumps have chips it
identifies their efficiency. Upon transition of one of the

1. On the latest reachstacker models there are fuel systems which are
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 $\pi^4$, $\pi^5$ won’t work, it blocks operation of hydraulic distributors (positions; $p^4$, $p^5$) and, therefore, all hydraulic system. Positions $p^4$, $p^5$ 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 $p^3$ is a discharge; chip having got to this position remains there.

![Fig. 4. Integrated Petri net of $p_1$ position: $p_1^1$ – engine; $p_1^5$ – the pump with a productivity of 100 cm$^3$/min (coupled); $p_1^4$ – pump (attached implement) with a productivity of 38 cm$^3$/min; $p_1^6$ – hydraulic distributor (right); $p_1^7$ – hydraulic system of spreader; $p_1^8$ – hydraulic distributor of the right lifting cylinder; $p_1^9$ – hydraulic distributor of the cylinder of the arrow extension; $p_1^3$ – the pump with a productivity of 100 cm$^3$/min; $p_1^4$ – hydraulic distributor (left); $p_1^5$ – steering machine (orbitrol); $p_1^6$ – hydroaccumulator; $p_1^7$ – hydraulic distributor of the left lifting cylinder; $p_1^8$ – parking brake; $p_1^9$ – braking pressure; $\pi^1$ – drive of the pumps in motion; $\pi^2$ – rotation transfer to the attached implement pump; $\pi^3$ – increase/decrease in feed of the pump; $\pi^4$ – triggering of the electromagnetic control valve of the spreader hydraulic system; $\pi^5$ – triggering of the electromagnetic valve of the right cylinder of lifting arrow; $\pi^6$ – triggering of the electromagnetic control valve of the cylinder of the arrow extension; $\pi^7$ – valve opening of the steering machine (orbitrol); $\pi^8$ – valve opening of the steering machine (orbitrol); $\pi^9$ – valve triggering of the hydroaccumulator recharge; $\pi^{10}$ – triggering of the electromagnetic control valve of the cylinder of the arrow extension; $\pi^{11}$ – triggering of the electromagnetic valve of the left cylinder of lifting arrow; $\pi^{12}$ – equalizing of pressure in the lifting cylinders; $\pi^{13}$ – turning on of the parking brake; $\pi^{14}$ – pressure control in the hydraulic system; $\pi^{15}$ – valve opening of the hydroaccumulator.](image)

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 $\pi^8$) to the torque converter ($p^4$) which is idling ($\pi^7$). Depending on the control knob position ($p^5$) the signal is supplied to one of the transitions $\pi^6$ or $\pi^9$. The position $p^5$ 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 $p_2$ position (the operation of hydraulic cylinders of lifting) is considered in fig. 6. The model shows that the net has two conflictual positions: $p^4$, $p^5$. The conflict in a position $p^5$ 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 $p_1$ position: $p_1^1$ – engine; $p_1^5$ – torque converter; $p_1^4$ – electromagnetic valve of forward stroke; $p_1^6$ – electromagnetic valve of back stroke; $p_1^7$ – valve of forward stroke is open; $p_1^8$ – valve of back stroke is open; $p_1^3$ – the control knob; $\pi^1$ – rotation transfer from the engine; $\pi^2$ – torque converter operation at idle; $\pi^3$ – triggering of the electromagnetic valve of forward stroke; $\pi^4$ – triggering of the electromagnetic valve of back stroke; $\pi^5$ – crankshaft rotation in a clockwise direction (forward motion); $\pi^6$ – crankshaft rotation counterclockwise (backward movement).](image)

![Fig. 6. Integrated Petri net of $p_1$ position: $p_1^1$ – oil pressure in the hydraulic distributor; $p_1^5$ – subpiston cavity of the cylinder; $p_1^6$ – piston sealing; $p_1^7$ – over piston cavity of the cylinder; $\pi^2$ – valve opening; $\pi^3$ – pressure increasing in the subpiston cavity; $\pi^4$ – pressure increasing in the over piston cavity; $\pi^5$ – opening of the drain valve; $\pi^6$ – extension of rod of the hydraulic cylinder; $\pi^7$ – opening of bypass valves.](image)

![Fig. 6 a. Integrated Petri net of $p_1$ position: $p_1^1$ – seals are serviceable; $p_1^2$ – seals are efficient; $p_1^3$ – seals are inefficient; $\pi^2$ – pressure increasing in the subpiston cavity; $\pi^3$ – extension of rod of the hydraulic cylinder; $\pi^4$ – restart-up of hydraulic liquid in the over piston cavity.](image)
If the labels do not match, then the transition $s_i$ is initiated.

Position $p_1$ (fig. 6) is conflictual. If the seals are not operable the transition $s_2$ won't work, the transition $s_2^a$ will turn on and hydraulic liquid will come to the over cavity (position $s_2$), 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 $p_1$, $p_1^a$ and $p_1^b$. 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 $p_1^a$ 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. The model of functioning of hydraulic system of spreader (position $s_1$, fig. 1) is shown in fig. 8. The position $p_1$ has chip which shows presence of pressure of working liquid. In the absence of chip in position $p_1$ (pressure of working liquid) the model won't work. Working liquid under pressure ($p_1$) is supplied to electromagnetic valves (positions $p_7$, $p_{11}^a$, $p_4$, $p_1$). Depending on signal feeding by operator (position $p_1^a$) the corresponding transition is triggered ($s_1$, $s_2$, $s_3$). Transition $s_3$ 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 $p_6$. The chip in this position will be only if there is a turning on of all sensors, the scheme is collected (position $p_1$) 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 $p_4$, $p_4^a$, $p_4^b$. After fade in/out load handling bayons from the container fittings the transition $s_7$ 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 $p_7$).

In this model, there is a conflict situation - the position $p_1$, the conflict is solved by the operator depending on the need for an overload of 20 or 40 foot container.

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**Fig. 7a. Integrated net of $p_i$ position:** $p_i^a$ – pressure in the hydraulic distributor; $p_i^a$ – pressure in the hydraulic distributor is absent; $p_i^a$ – supply of pressure into the subpiston cavity of the hydraulic cylinder; $p_i^a$ – supply of pressure into the over piston cavity of the hydraulic cylinder.

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**Fig. 7.** Integrated Petri net of $p_i$ position: $p_i^a$ – joystick; $p_i^a$ – electromagnetic valve of the arrow extension; $p_i^a$ – electromagnetic valve of the arrow assembly; $p_i^a$ – oil pressure in the hydraulic distributor; $p_i^a$ – subpiston cavity of cylinder; $p_i^a$ – over piston cavity of cylinder; $p_i^a$ – piston seals; $p_i^a$ – control sensor of arrow sortie; $p_i^a$ – blocking of movement of the piston rod; $s_i$ – signal on the arrow extension; $s_i^a$ – signal on the arrow assembly; $s_i^a$ – opening of closing of the valve; $s_i^a$ – pressure increasing of the subpiston cavity; $s_i^a$ – pressure increasing of the over piston cavity; $s_i^a$ – cylinder rod movement; $s_i^a$ – triggering of the sensor of the maximum sortie; $s_i^a$ – triggering of the sensor of the minimum sortie.

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**Fig. 8.** Integrated Petri net of $p_i$ position: $p_i^a$ – oil pressure in the hydraulic system; $p_i^a$ – electromagnetic valve of cylinders of spreader extension/shift; $p_i^a$ – electromagnetic valve of cylinders of the spreader moving (positioning); $p_i^a$ – electromagnetic valve of the hydraulic motor of the spreader rotation; $p_i^a$ – electromagnetic valve of cylinders of opening/closing of load handling bayons; $p_i^a$ – induction sensors; $p_i^a$ – joystick; $p_i^a$ – hydraulic oil pressure in the cylinders of spreader extension/shift; $p_i^a$ – hydraulic oil pressure in the cylinder of the spreader moving; $p_i^a$ – hydraulic oil pressure in the hydraulic motor; $p_i^a$ – hydraulic oil pressure in the cylinder of opening/closing of load handling bayons; $p_i^a$ – assembled electrochain; $p_i^a$ – spreader feet are moved apart/assembled; $p_i^a$ – spreader in the set position relative to the horizontal; $p_i^a$ – spreader in the set position relative to the vertical; $p_i^a$ – bayons are closed/opened; $p_i^a$ – signal of spreader readiness to work; $s_i^a$ – supply of pressure of hydraulic fluid to the spreader hydraulic system; $s_i^a$ – triggering of electromagnetic valve of cylinders of spreader extension/shift; $s_i^a$ – triggering of electromagnetic valve of the spreader moving; $s_i^a$ – triggering of electromagnetic valve of the hydraulic motor of the spreader rotation; $s_i^a$ – triggering of electromagnetic valve of cylinders of opening/closing of load handling bayons; $s_i^a$ – short circuit of an electrochain; $s_i^a$ – extension/shift of the spreader feet; $s_i^a$ – the spreader moving (positioning); $s_i^a$ – the spreader moving (positioning).

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1 $p_{sub}$ – pressure in the subpiston cavity; $p_{over}$ – pressure in the over piston cavity

2 $p_{over}$ – pressure in the hydraulic system; $p_{sub}$ – the set pressure in the over piston cavity
spreader rotation; \( \pi_{9}^{a} \) – rotation of load handling bayonets; \( \pi_{12}^{a} \) – input/output of the spreader from fittings; \( \pi_{12}^{a} \) – triggering of time relay.

Integrated net of \( p_{6} \) position (electrical system of the reachstacker) is presented in fig. 9. In this model the position \( p_{7}^{a}, p_{8}^{a}, p_{9}^{a} \) have the chips imitating operating state of a position. Transition \( \pi_{8}^{a} \) will work if two chips from positions \( p_{7}^{a}, p_{9}^{a} \) come to it. Position \( p_{7}^{a} \) is conflictual. If the button of emergency stop isn’t switched on, the chip will initiate the transition \( \pi_{7}^{a} \), otherwise, the chip will go to the transition \( \pi_{2}^{a} \) 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 \( p_{1}^{a}, p_{2}^{a}, p_{3}^{a}, p_{4}^{a} \) 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 \( \pi_{9}^{a} \) won’t be initiated, the spreader will be in a non-working state.

### 3. The Solution of the Optimization Problem

Chips from the transitions \( \pi_{6}^{a}, \pi_{6}^{b}, \pi_{8}^{a}, \pi_{10}^{a} \) come to positions \( p_{9}^{a} \). In the position \( p_{9}^{a} \) 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.

4 signals come to the position \( p_{9}^{a} \). In the integrated net in the position \( p_{5}^{a} \) (fig. 10a) the chip will have dimension 4. The transition \( \pi_{10}^{a} \) 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 \( \pi_{1}^{a} \) which will block electromagnetic valve of the hydraulic system of the spreader.

When the chip gets to the position \( p_{3}^{a} \), the signal is supplied on the transition \( \pi_{12}^{a} \), after its triggering, the signal on turn of the bayonets comes. The transitions \( \pi_{1}^{a} \) and \( \pi_{9}^{a} \) have labels \( \zeta \) and \( \xi \), respectively, and at the coincidence of these labels the transitions will work. The transitions \( \pi_{3}^{a} \) and \( \pi_{12}^{a} \) also have labels \( \zeta \) and \( \xi \), 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.

References