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USING THE PETRI NETS FOR FORMING THE TECHNOLOGICAL LINES OF THE PASSENGER TRAINS PROCESSING IN UKRAINE

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Abstract: *Despite the large number of publications, which authors use the mathematical apparatus of Petri nets for the transportation systems studies, there are still no such researches of technological processing lines for passenger trains on the territory of passenger complexes that aim to improve trains processing technology. In this article, we present simulation models of technological processing lines for passenger trains of different categories developed with the use of Petri nets. The structure of proposed simulation models is based on real time parallel-operating objects. Such an approach allows maximizing similarity of developed models and the simulated objects; in this way we achieve the increased adequacy of the obtained models. The article presents an interface of developed models and examples of their functioning under conditions of different input parameters, as well as the results of their use in order to reduce the passenger trains processing time. The proposed models are generic and could be applied for simulation of passenger trains processing at any station of Ukraine.*

Key words: *passenger complexes, passenger technical station, Petri nets, simulation model, technological line.*

1. Introduction

The contemporary transportation market requires from the railway transport of Ukraine the high level of quality, regularity and reliability of transport services (Prymachenko, 2015). In the conditions of market economy one of the main factors that contributes to the establishing and securing a leading position at the transportation market is the competitiveness of railway transport (Lomotko, 2008; Alyoshinskiy et al., 2012). In addition, the transport infrastructure state of Ukraine should comply with the requirements of the European Union. Under the existing state of the Ukrainian railways technical equipment that needs renewals at almost 80%, there also arises the problem of optimization of the passenger complexes (PC) functioning process to achieve the effective organization of transportation process.

Satisfaction of the Ukrainian people requirements in passenger transportation providing the appropriate level of the service quality is the main goal of the railway transport management at the state level in Ukraine. Passenger transportations must not be only convenient and affordable, but they should also meet the requirements of safety and high-speed delivery in order to ensure the competitiveness of the railway transport.

One of the priorities of the Ukrainian transport industry is improving the financial condition of the railway transport. The modern society puts forward new demands on transport services because the railway transport should be able to meet all the needs in full volume. In terms of the rolling stock lack, inappropriateness to the requirements of the most of the passengers transport infrastructure and increased competition, especially from the side of the road transport, the problem becomes a very complex one because it should be solved considering an improvement of the efficiency of passenger transportation process using limited financial resources.

In this way, the task of improving the financial condition of passenger transportation by improving the organization of transport through the development of railways in modern conditions could be implemented through solving the scientific problems of the losses reduction in the passenger sector, an optimization of the of rolling stock use, the increase of the efficiency of passengers transportation technological processes.

The railway transport improvements should be sent generally on maintenance of passenger trains and wagons. The main improvement tasks regarding the technology of the passenger trains and wagons processing are the reduction of technological operations duration, the decrease of the interoperable downtime duration for passenger wagons avoiding the traveling delays and minimizing transportation costs, ease of the wagons and trains replacement during the circulation in the places of destination.

In this paper we propose simulation models, which could be used in order to enhance the railways efficiency through increasing the efficiency of the passenger trains processing at the passenger station (PS) and passenger technical stations (PTS) as elements of PC.

2. Characteristics of contemporary railway passengers transport of Ukraine

Rail transport in Ukraine is the most important supporting sector of industrial production sector, providing all kinds of public transport both freight and passenger, promotes the territorial labor dissemination; it becomes an active factor in the formation of specialization of economic activity in some regions of Ukraine. According to the transported volume of cargos and passengers, the Ukrainian railway transport is ranked fourth after Chinese, Russian and Indian railways (MIU, 2016).

Under the conditions of relatively high prices of petroleum products, railway transport has special advantages to other forms of transport due to the extensive use of electricity (48% of Ukrainian railways are electrified). This fact significantly increases the competitiveness of the rail transport in Ukraine.

It is expected that in 2020 the volume of passengers transported by Ukrainian railways will increase compared to 2014 at 11,7%, which amount to 497,7 million passengers a year. The analysis of the key indicators of passenger railway transport of Ukraine (the number of passengers and passengers turnover) since 1991 has shown an increase in demand for rail transport, according to official statistics of the "Ukrainian Railways" private corporation. The largest volume of passengers transportation in local and direct connections were recorded in 1994 (over 600 million passengers), and then observed trend of cutting transportation due to lower living standards, but in recent years the number of passengers increases gradually. The level of real income of the population of Ukraine for 2002-2015 years was analyzed (SSSU, 2015). The obtained results allow to state that dependence of passenger traffic in the local and direct connection to the living standards of Ukrainians is directly proportional.

A financial position of the rail transport depends in the first place on the volume of services provided to the population. For example, increasing the number of passengers by 2015 led to increased revenue railways by 1,8% compared to 2014 year. Since 1992, passenger turnover declines continuously, especially abrupt change of dynamics could be observed since 1994, generally this figure fell almost 35% in the period from 1992 to 2002. A significant reduction in passengers was observed in 1999 (62% in local and direct connections), which was to a greater extent caused by reduced average travel distance. Granting the right to free travel on local trains and direct connections to children under 16 years in 2002 affected the growth of the passengers number. In 2006-2007, it was the raising of tariffs on passenger transportation, which influenced the decrease in passenger and in 2009 this figure fell because of the economic crisis that significantly affected the solvency of the population. Thus, all of the factors slowed the growth of quantitative indicators of Ukrainian railway transport in passenger traffic and direct local train largely because of the complexity of the financial condition of the population in the post-soviet period.

The results of transportation process evaluation for various modes of passenger transport in Ukraine showed a keen competition between the road transport (44,292% of overall passengers volume) and the rail transport (44,298% of overall passengers volume).

3. Literature review

Analyzing the passenger stations technological process, contemporary researchers have generally focused on the throughput increasing, the execution of the trains schedule, an implementation of the planned performance indicators.

At the present stage of development of railway transport in Ukraine there exists a trend of shortage of passenger cars and poor technical condition of existing rolling stock; the majority of technical devices at substations require upgrading (Alyoshinskiy et al., 2012). Therefore, at first it is necessary to pay attention to the possibility of reducing the costs to release funds for further upgrade of the technical equipment of stations and rolling stock. Thus, the issues of the development of rational technological processes of passenger trains servicing at the PS, determination of the optimal directions for the station track development, estimation of the rational employees number, rationalization of the technical equipment are particularly relevant at the moment.

In the contemporary research theories and principles of the PC functioning, special attention is paid to the improvement of economic methods (Nash, 2015; Li et al., 2015; Lingaitisa and Sinkevičiusb, 2014), development of relations between the railway companies, the consumers of their services and the executive authorities of all levels (Zhu J. et al., 2014; Nedeliakova et al., 2015), creation of the optimal tariff policy (Shaoni et al., 2015; Zhu Y.T. et al., 2014; Razumovskaya et al., 2014).

The efficiency of passenger transport was an object of research for scientists of the Russian Federation and Belarus, such as Abramov et al. (2001), Belenkiy and Silaev (1986), Bescheva (1968, 1984), Marchuk (2003, 2004) and others, for the number of Ukrainian scientists – Kulaev (2006), Zagorulko et al. (2011), Vorkut (2005), and others. In recent years, the research on the optimization of passenger transport was carried out by Aksenov (2004), concerning the establishment of the economic management mechanism of PC, by Prokhorenko (2008) on improving the functioning processes of passenger technical stations, by Eremina (2009) regarding the competitiveness of passenger transport by introducing high-speed traffic and others (Luchkov and Berdnik, 2010; Lukhanin et al., 2007; Butko and Prokhorenko, 2010; Butko and Prokhorenko, 2013).

4. Modeling the servicing process on the basis of the Petri nets apparatus

PS is one of the elements of railway transport system, which could be defined as a complex socio-economic subsystem characterized by a clearly determined execution order. As a technological system, PS consists of series of continuously interacting elements: the input neck, admission districts, transit districts, administration districts, the output neck, grading districts, inspection and equipment stations, the railway passengers station, passenger devices, office facilities, etc. The individual elements of PS cannot be separated out of the system if the problem of obtaining the rational technological scheme is being solved. The situation in each subsystem is constantly changing, in addition, the subsystems functioning processes are uneven and are characterized by the probabilistic nature of the processes of trains, wagons and locomotives arrival. A significant feature of PS is its diversity and a strict sequence of technological operations performance. For the Ukrainian railways PS, it is necessary to determine the rational processing technology of passenger trains of different categories in order to minimize the time of the trains processing at the station.

To solve this problem we developed the model of technological lines of processing of various categories of passenger trains using the Petri nets apparatus. This apparatus was used because most of the processes of the trains handling at the station occur in parallel (according to the processes schedules: technical inspections, equipping processes, unload and load of post and luggage, disembarkation and embarkation of passengers, the locomotive crews changing, the brakes testing, the wagons hitching and unhitching, the locomotives changing, etc.) (UZ, 2005). The main feature of the Petri nets is that they are based on a particular technology that allows to combine analytical calculations for the certain system elements with simulations of the elements interaction, and thus to gain new knowledge about the behavior of all the elements of the system. This feature allows to use the Petri nets as a simulation tool for the parallel structures studies (Kotov, 1984). Such simulations help to determine a load for a particular technological element of the PS and the need for technical means, as well as to make the analysis of the PS technological process.

In the Petri net models, the concepts of conditions and events are used; conditions are indicated by the positions (p_i), and events – by transitions (t_i) (Peterson, 2008).

The macro-level model of the transit passenger trains processing with a change of locomotives and a crew is shown at Fig. 1. The train arrival is reflected by the transition *t*1, positions *p*2 means a readiness to change the locomotive which is fed from the locomotive depot (*p*10). The needs for locomotive crews are modeled in the transitions *t*2 – *t*6. Position *p*3 reflects an intention to put on groups of wagons, serviced at the PTS (*p*11) or to uncouple from the train and the fence to the PTS or available station tracks (*t*3 – *t*7). Position *p*4 shows the readiness of the brigade for the technical inspection and loadout (*t*4 – *t*8) at the point of the technical inspection (*p*20). Position *p*5 reflects the readiness for loading and unloading of post and baggage (*t*5 – *t*9) by the postal and baggage workers (*p*21). Position *p*22 means the readiness for the embarkation and disembarkation of passengers (*t*13 and *t*14). After the change of the locomotive and a crew, a test of the brakes is performed (*t*11, *t*12), after which the train is ready to departure from the station (*t*10).

The macro-level models of technological processing lines for transit trains without change of the locomotive and a crew, and with the change of locomotive were constructed similarly.

For the train arrived at the station for its formation, it was developed the model shown at Fig. 2. After the train arrival at the station (*t*1), the following operations are performed in parallel: supply of the shunting locomotive from the PTS (*p*19), uncoupling of the train locomotive (*t*6) and its movement to the locomotive depot (*p*20), unloading of post and baggage (*t*3 – *t*7) by the postal and baggage workers (*p*10), technical inspections (*t*4 – *t*8) by the workers of the technical inspection (*p*18), the passengers disembarking (*t*5 – *t*9). After the technical inspection brigade is free (*p*18), the shunting locomotive is put on (*p*11), the brakes tests are made (*t*11, *t*12) and the crew is shifted to the PTS.

At the departure of the train of own formation, the wagons are supplied with the PTS export locomotive that after implementation of its operations is set out and goes back to the reception district of the PS; other operations are similar to that shown at Fig. 2.

If the described models of the technological processes are combined, the universal model of the PC functioning along with the PTS could be obtained. This model could be used for the studies of the trains processing dynamics, in the procedures of estimation of the required number of workers in inspection teams, post and baggage workers on the basis of obtained parameters of time delays for a particular element of any subsystem. Before simulation procedures star, all the elements are taken as free, and then definite labels representing the input parameters are given to the model elements. In order to provide the quantitative analysis, the numerical time parameters are inputted for each technological operation.

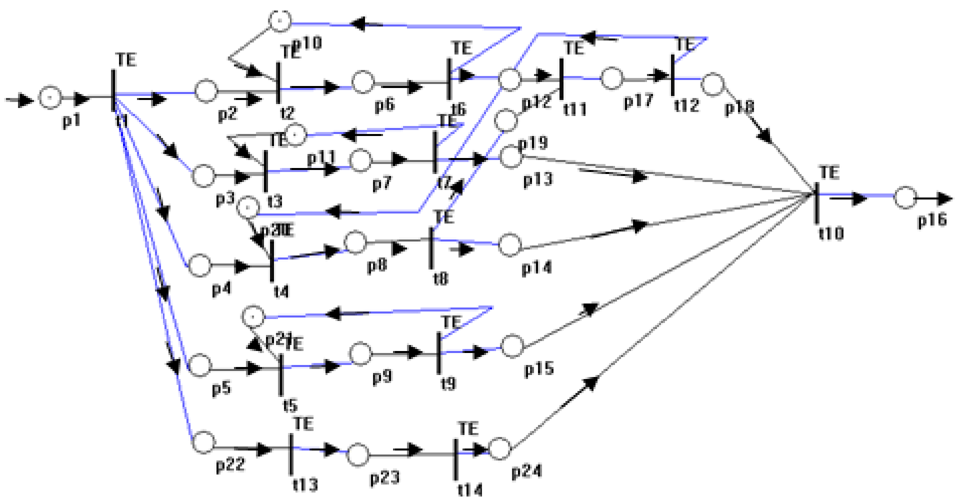

Fig. 1. The macro-level model of the technological processing line for the transit trains with the possibility of locomotives and a crew change

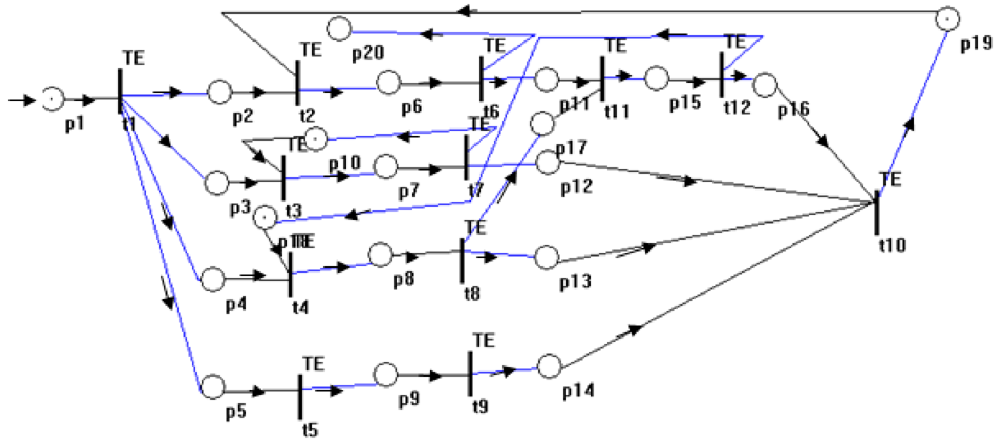

Fig. 2. The macro-level model of the technological processing line of the own formation trains on arrival

Fragment of the PC model is shown at Fig. 3, whereas as *p*1 – *p*8 positions the adjoining spans are marked, the number of which could be changed; transition *t*9 means the occupation of the station input neck; position *p*11 reflects the number of the occupied station tracks, transition *t*10 distributes the trains into categories: transit without the change of the locomotive and a crew (*p*13), transit with the change of the locomotive (*p*27), etc., according to the above mentioned categories.

For the case shown at Fig. 3, through the neck of the reception district of the given PC 110 trains (*p*1 – *p*8) were emitted during one day (1440 min.), at that an occupation level of the neck was 300 min., its loading amounted to 20,83% of simulation time. During 501 min. (34,79% of simulation time) the transition *t*9 was blocked because of the impossibility of admission at the reception district of more than *k* trains (for the shown example *k* = 7). During the simulated period 10 transit trains were received without the locomotive changing, 30 transit trains were serviced without changing the locomotive and a crew, for 22 transit trains a change of the locomotive and a crew was performed, 26 trains of own formation were received and 12 trains of own formation were sent from the station according to initial data.

During the simulation procedures, the system status may be fixed at any time, and its elements could be changed. The optimal number of teams at the inspection district, of post and baggage workers, of occupied tracks at the station, as well as the optimal duration of each technological operation could be estimated with the use of the proposed PS simulation model.

The proposed model could be characterized as a universal one, because it can be used in order to study the technology of any given station functioning, as well as in order to explore the interactions between stations for a set of stations in the selected direction. The developed macro-level model is particularly relevant for the studies of the towed passenger wagons processing (Balaka and Sivakoneva, 2014); in this case the model helps to determine the time spent by wagons at a given station and to plan more effective routes. While using the railway infrastructure by tourist carriers in interaction with tourist operators, the use of the PC macro-level model could help to adjust delivery time and make the correct traffic schedule.

For the procedures of the PC model implementation, the PTS functioning processes were simulated in more detail (Fig. 4). Simulations of PC with the use this model were conducted considering disadvantages discovered as a result of researches of the PC incoming and outgoing necks, and of the PTS technological lines for the processing of passenger trains of different categories.

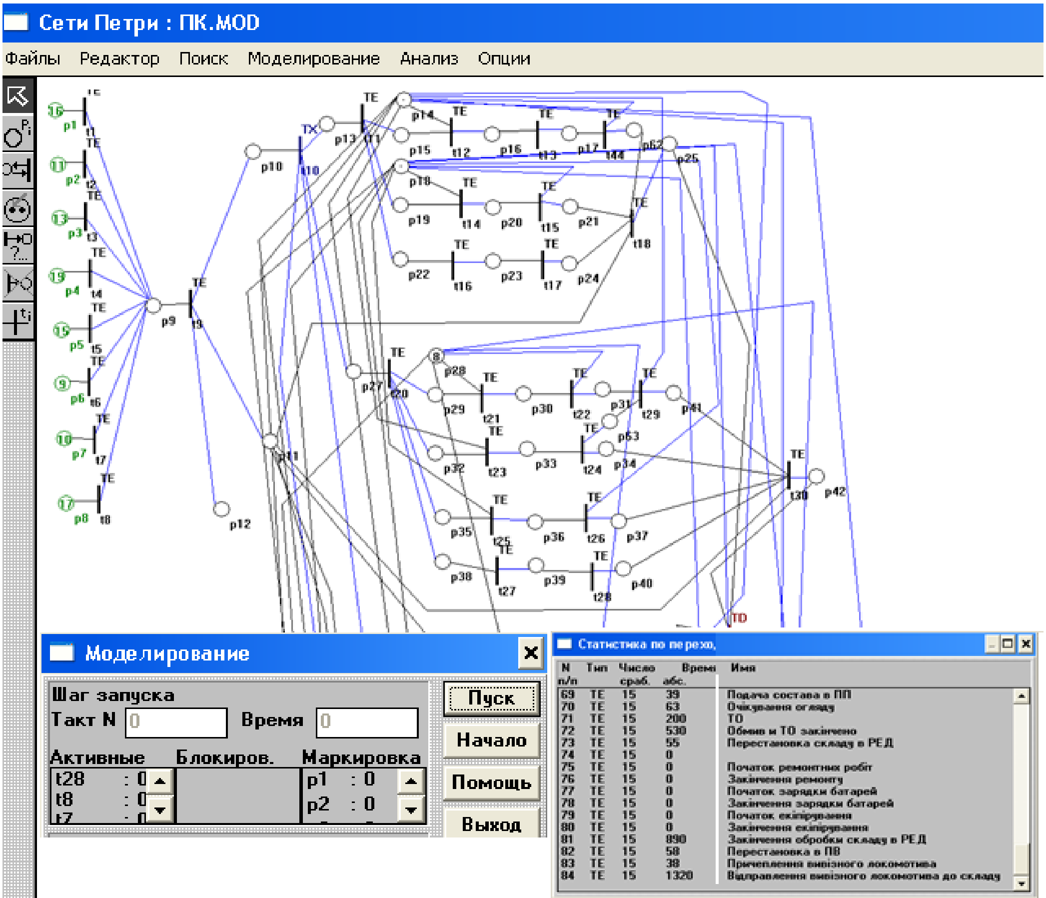

Fig. 3. A fragment of the used software interface for the PC modeling at macro-level

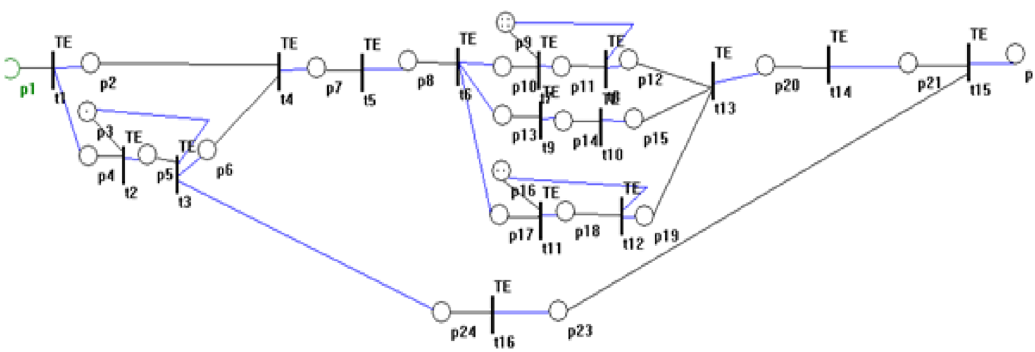

Fig. 4. The macro-level model of the PTS as a part of the PC models

As a result of simulations, it was found that the duration of the transit train processing with the change of the locomotive could be reduced to 4,34 min. due to parallel execution of technological operations during coupling and decoupling of wagons (while decoupling the passenger car from the train head, the train locomotive could be decoupled together with the group of cars that should be decoupled from the train at the given station; their processing could be performed after departure of the train locomotive with the wagons from the reception track; the same technology could be implemented while coupling cars in the train head – beforehand prepared train locomotive with the wagons could be processed simultaneously). Duration of the processing procedures for the train of the own formation on its arrival could be reduced to 28,09 min. (as a result of parallel execution of such operations as decoupling of the train locomotive and the post and baggage cars), time for processing of the train at PTS in the formation point could be decreased on 45,83 min. (due to parallel execution in the repair depot of such operations as internal repair of wagons, batteries charging, equipping with coal and water).

In order to study the process of the passenger train departure according to the schedule of passenger trains, we developed a model that allow to simulate an operation of sending the train from the station at a certain time on a certain date. To do this we combined a model of the passenger trains scheduling process with the PC model; as a result, we've obtained a new simulation model of the PC, that allows simulating the moments of arrival and departure in accordance with the trains schedule (Fig. 5).

To study the interaction of stations in the given direction, we have developed a general model of the railway network of Ukraine on the base of the existing location of train stations, where local and long-distance passenger trains stop according to the schedule. In the Petri net model, transactions are the folded models of the PC functioning according to the traffic schedule, and positions are the stations that are passed by the trains. The developed model allow to determine the possible delays that occur in the transport system, taking into account various probability factors that make possible to simulate technological processes basing not on mean or standard duration values of technological

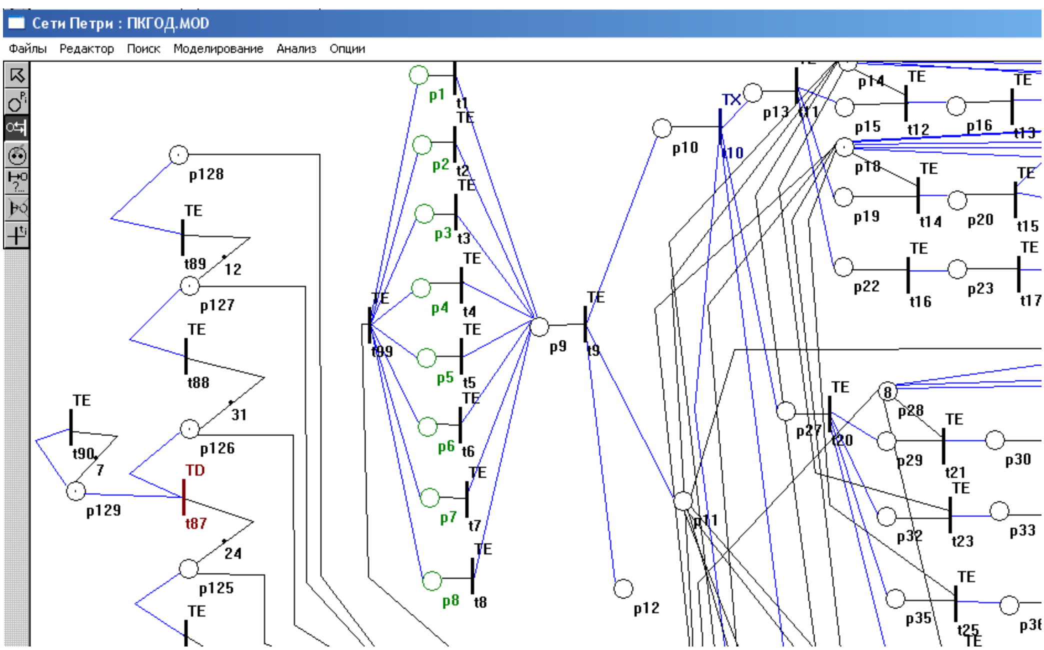

Fig. 5. A fragment of the PC macro-level model with the schedule

operations, but on rates corresponding to the situation. This makes possible to study the dynamics of the transport system functioning, to determine duration of the trains processing procedures in a more accurate way, to eliminate the "bottlenecks" of the technological processes, and thus – to ensure the efficiency and quality indices of the PC functioning.

5. Conclusions

Since technological lines of passenger trains processing are the elements limiting the time, spent by trains at the station, which proportionally affects the turnaround time of rolling stock, it is possible to adjust the time, spent by trains at stations, taking into account the traffic schedule and the trains formation plan. Simulations on the basis of the proposed Petri nets models help to obtain important information about structure and dynamic behavior of the PC as elements of the transport system.

The developed models could be used in order to study the technological lines of the passenger trains processing when changing the number of cars and locomotives, number of workers and free station tracks, the PTS throughput value, etc. With the use of the developed models it is possible to define queues and delays of the simulated system, to consider various probabilistic factors that allow researchers to model technological processes on the basis of indices values which correspond to a respective situation. This gives an opportunity to conduct research of the PC processes dynamics and helps to take into account duration of the trains processing procedures.

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