

Evgen Aleshinskiy

Transport Systems and Logistics Department, Ukrainian State University of Railway  
Transport

Vitalii Naumov (vnaumov@pk.edu.pl)

Faculty of Civil Engineering, Cracow University of Technology

Oksana Pestremenko-Skripka

Railway Stations and Junctions Department, Ukrainian State University of Railway  
Transport

## THE MODELLING OF TECHNOLOGICAL PROCESSES AT BORDER TRANSFER STATIONS IN UKRAINE

---

### MODELOWANIE PROCESÓW TECHNOLOGICZNYCH NA PRZEJŚCIACH GRANICZNYCH NA UKRAINIE

#### Abstract

In the process of the transfer of railway wagons between countries, the main role in processing the flow of cargo is assigned to a border transfer station. Additional border operations – such as customs, environmental, veterinary, phytosanitary, and epidemiological control – have led to a significant increase in the number of detained railway wagons. As a result of these increases, delays in the deliveries of both import and export cargoes have also increased. Reducing the duration of the delivery of goods by rail could be achieved through reductions in the times taken to process trains at border transfer stations – risk management systems based on the principle of selective survey operations in international traffic processing provide such an opportunity.

**Keywords:** border transfer station, simulations, Petri nets, risk management system

#### Streszczenie

W procesie przemieszczania wagonów kolejowych pomiędzy krajami główna rola w przetwarzaniu przepływu towarów jest przypisana do stacji przejść granicznych. Dodatkowe operacje graniczne – takie jak kontrola celna, środowiskowa, weterynaryjna, fitosanitarna oraz epidemiologiczna – przyczyniają się do znacznego wzrostu liczby zatrzymanych wagonów kolejowych. W wyniku tych zatrzymań wzrastają również opóźnienia w dostawach zarówno towarów importowanych, jak i eksportowych. Skrócenie czasu dostawy towarów koleją można osiągnąć poprzez zmniejszenie czasu potrzebnego na obsługę pociągów na przejściach granicznych – stwarzają taką możliwość systemy zarządzania ryzykiem w międzynarodowym ruchu kolejowym bazujące się na zasadach selektywnych badań.

**Słowa kluczowe:** stacje przejść granicznych, symulacje, sieci Petriego, system zarządzania ryzykiem

## 1. Introduction

European integration processes in Ukraine should be based on the advanced principles of effective systems of governance. This requires a preliminary analysis of the compliance of these processes with national government policy and requires organisational and legal support. Due to the existing trends in global technological development, Ukraine should provide facilitating procedures for the passage of import and export cargoes through border transfer stations (BTS) with regard to rail freight. Therefore, Ukraine should soon adopt the appropriate European standards to which it has formally joined and which are captured in such major international acts as the International Convention on harmonization and simplification of customs procedures (Kyoto Convention) and the Resolution of the Customs Cooperation Council concerning the framework standards of safety and harmonization of the international trade. These contemporary principles implemented in the system of management and risk analysis could be used as effective tools for controlling the stability of Ukraine's foreign trade activities.

The continuous increase in foreign trade requires the continual improvement of international transport and the improvement of cross-border transfer stations. In rail transport, in which the operations of all the structural parts are interconnected, difficulties that may arise at certain BTS can seriously influence the overall efficiency of the railway network operation.

Despite the fact that since 2014 the volume of international traffic at railway transport of Ukraine has significantly reduced due to the Russian occupation of Crimea and military aggression in Donetsk and Luhansk regions, the unproductive downtime at the border stations has not decreased. Additionally, in 2018, the European Union plans to close the project on modernization and the construction of border checkpoints with Ukraine, which was launched in 2014. This project was aimed at helping to integrate the Ukrainian economy with neighbouring countries – Poland, Hungary, Slovakia, and Romania. In the opinion of the EU, the BTS modernisation project aimed at shortening the periods of border crossing and improving customs procedures, did not achieve its goals.

Currently, the turnaround time of trains at BTS is determined by the duration of paperwork, customs, and border inspection, which is usually several times longer than the time required to perform the technical and commercial operations. During the period from 2010 to 2017, a significant proportion (47.8%) of the total number of detained rail freight wagons make units that were detained by a carriage service sector, 24,3% – cars that were delayed by commercial service management (handling, cargo packaging breach, etc.), 13,3% – cars detained by the customs. These delays significantly affect the downtime and the number of detained rail freight wagons, and together with a shortage of rolling stock, this creates significant problems for both the Ukrainian Railroad Company (Ukrzaliznytsia) and cargo owners.

In order to speed up the functioning of checkpoints and reduce the downtime resulting from the delay of rail freight wagons, it is necessary to improve the operation of customs checkpoints, to adjust their parameters to common European standards of technology and to implement the use of electronic information and documents in the distribution of goods.

This paper aims to propose a tool for the simulation of the technological processes which occur at BTS and to use the simulation results for risk estimations while managing the railway transport system.

## 2. Literature review

At present, the main areas of the research focus on the optimisation of cargo delivery systems which uses computer simulations and various mathematical methods and models of the optimisation of international rail freight traffic.

One of the first BTS operation optimisation models was created by K. Mironenko in order to solve the problem of how to reduce the duration of stay at the wagon reloading stations. This model was a mathematical model of the reloading process that took into account the priority of freight wagons to the loading fronts, cargo handling complexity, and the static load of rail freight wagons [1].

As a new impulse to research the problems relating to international rail freight traffic, a system of international transport corridors was developed in 1991 and approved in 1994 [2]. In Ukraine, many studies were carried out after the introduction of the resolution on the Approval of the Concept of Creation and Operation of a National Network of Transport Corridors in Ukraine by the Cabinet of Ministers of Ukraine no. 821 from 08.04.1997 [3]. The main scientific and practical merit of solving the problem of the development of international transport corridors in Ukraine belongs to G. Kirpa [4, 5]. Recently, the relevance of studies for improving the BTS operational processes at Ukrainian border stations has also been underlined in publications [6] and [7].

The most relevant areas of study in the field of BTS operation include the analysis of transport system reliability, the development of the efficient (or even optimal) sequences of operations for implementing transportation processes including international rail transport technological schemes, the allocation of capacity for international railway transport [8-15]. Issues relating to the computer automation of border stations are discussed in [8]; furthermore, the authors of [9] have discussed problems regarding increasing the performance of intermodal railway freight terminals.

Current research suggests that excessive delay of rail freight wagons at border stations reduces the reliability of the international transport system and may lead to a reorientation of international transit cargo flows in order to bypass the territory of Ukraine. However, it should be noted that until 2007, the problem of optimising the border and customs operations to reduce downtime and increase the transfer capacity of border stations was not considered in studies of Ukrainian scientists. The problem has been studied in detail in thesis [12]; however, the operations of control services at border stations were not considered sufficiently. The task of improving the information subsystem of BTS has been addressed in thesis [13]; however, the possibility of introducing modern systems analysis and risk management tools for cargo handling procedures at BTS has not been taken into consideration.

The mentioned literature analysis leads to the conclusion that, as a result of the uncertain nature of technological processes at railway transport and unpredictable nature of demand for transport services, the problem of improving freight distribution systems under the terms of reducing the freight units' downtime must be solved with the use of risk management tools.

### 3. Simulation model of the process of servicing the wagons at Ukrainian BTS

To develop the simulation model, a structured and logical framework for cooperation between the operational lines at border stations has been formed. This can be represented as a diagram of the operations for processing trains which combines fifteen major elements, most of which are the technical customs operations (Fig. 1).

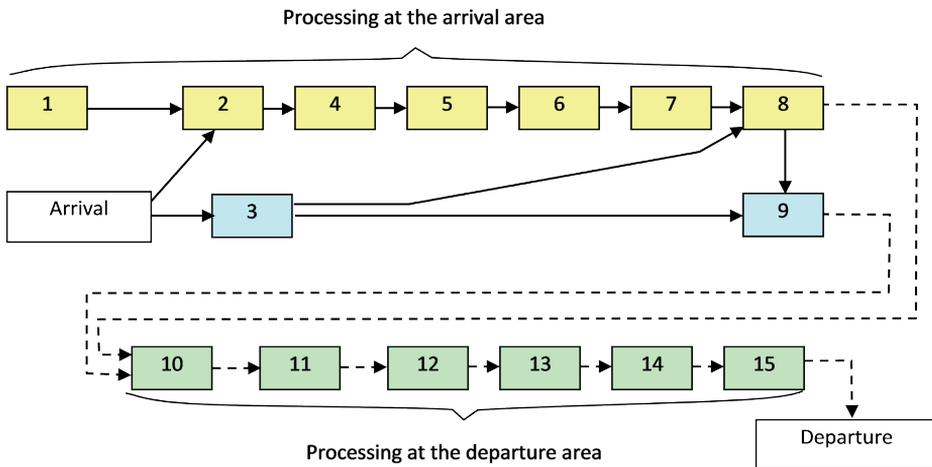


Fig. 1. Structural scheme of information processing at BTS

The numbered blocks on Fig. 1 present the generalised technical operations listed in Table 1.

The most restrictive operations at BTS are the operations that are related to customs control and documents processing. This leads to frequent delays of rail freight wagons at transfer stations. Therefore, it is necessary to list the main reasons why the freight wagons cannot simply pass a border station and are instead being delayed.

More than fifty reasons for delays have been found at Ukrainian border stations; the most frequent fourteen reasons (which make up more than 74% of the additional idle time) are listed in Table 2.

The listed delays in customs operations significantly increase the duration of freight wagon processing at the Ukrainian BTS. Sometimes, there are the cases that may even stop entry at the customs border and cause the refusal of freight wagons and cargo.

Table 1. List of the railway processing operations and respective information flows

Operation number	Operation content
1	receiving the data at the information system in the form of the train transfer declaration, discarding the train
2	delivery of train documents to technical office
3	technical and commercial check control of the train
4	checking the train documents according to the list of discarding
5	checking of data, providing updates
6	checking by veterinary service, phytosanitary and sanitary service, ecological and radiological testing, frontier services
7	testing the veracity of documents, testing the availability of appropriate customs payments
8	checking the train documents by customs services
9	processing operations relating to the train composition (sorting, formation of trains, shunting, coupling, uncoupling cars, loading and unloading or reloading, replacement of cars, etc.)
10	transfer of the cargo customs declaration by declarants and producing electronic copies
11	checking the declaration and its copies by customs experts
12	making adjustments in the information system concerning detached freight wagons in order to produce the train transferring declaration
13	checking the train documents by the cargo customs services
14	selecting the proper train transfer declaration and train documents
15	converting and delivering the train documents, sending the data to the next station

Table 2. The main reasons for freight wagon delays at BTS

Operation code	Reasons for delay of wagons
X1	customs inspection
X2	customs registration
X3	no information received from the customs administration
X4	technical and commercial failure of a freight wagon
X5	data mismatch in the transportation and technical bill and the cargo customs declaration
X6	delay caused by phytosanitary, veterinary, sanitary, and frontier services
X7	delay caused by ecological and radiological testing services
X8	improper execution of documents
X9	absence or closure of a dispatcher's code
X10	dividing the routes
X11	no information found in the central database
X12	no invoice received
X13	other reasons (for example, groundless non-acceptance of goods by a neighbouring state)
X14	delays according to additional orders (e.g. a temporary ban on the import-export operations)

For a detailed analysis of customs procedures, a simulation model of a border station has been developed. For this model, a system of parallel information processing facilities and a system of simultaneously operating facilities should be simulated. Petri nets models are some of the most advanced approaches that are currently available which enable the incorporation of such systems. Petri nets are widely used for simulations of railway transport systems. The most recent studies [16–19] use this tool for solving problems of forming the technological lines of the passenger trains, security and vulnerability analysis on time protocol of the railway network, etc. It also worth mentioning that Petri nets are one of the most appropriate simulation tools for studies using statistical modelling methods. This mathematical tool monitors the status of all the model elements in real time and provides values of all simulated statistical parameters used for the model description.

The developed generalised macro-level model of the line for the processing of rail freight wagons, documents and information flows at BTS is shown in Fig. 2. In this model, the major transitions are numbered according to the list of operations on arrival and departure (Fig. 1). Shaded positions (X1, X2, etc.) indicate the main causes of wagon delays at BTS at the relevant stages of processing.

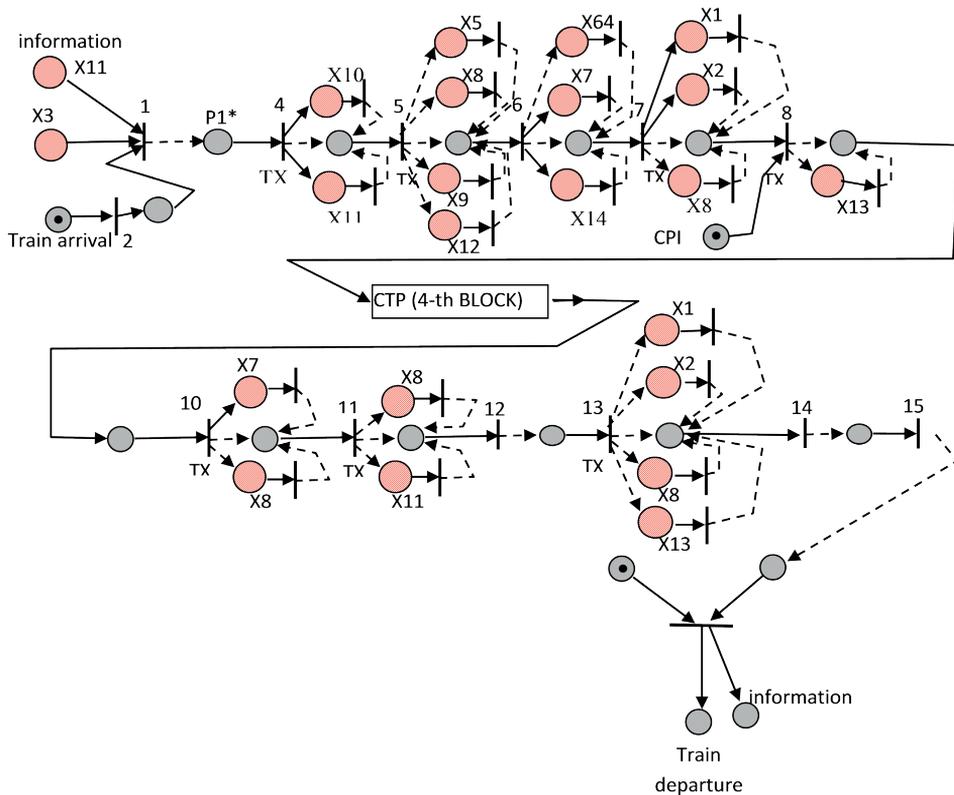


Fig. 2. Macro-level model of cargo handling processes relating to customs at BTS

The presented model operates in the following way. With the arrival of the train at the station (chip in the position P1), the availability of free tracks for receiving trains is checked (the position P3 has a capacity limit equal to the number of tracks). After the train is accepted, the locomotive is uncoupled and is sent to the depot. The technical point inspection (TPI) and commercial point inspection (CPI) then commence. However, these operations are performed in parallel, and several servicing teams may be able to process several trains simultaneously, thus removing the need for them to wait in line. Along with maintenance TPI and CPI operations, customs operations are also commenced. Unless there is any delay, the operations from 1 to 15 listed above are performed consistently. However, real-world observations demonstrate that the processing of arrival and departure operations of trains may be delayed at each stage (shaded position) – the probability of which is determined by transitions of TX-type. A list of the main causes of delay is presented in Table 2.

As shown in Fig. 2, the first delay may occur before the customs inspection. First of all, email customs administration may be lacking (X3) and there may be a lack of information in the database of the information system (X11). If email customs administration and information about wagons have been entered in the database (the presence of chips at positions X3 and X11), a review starts according to the provided data (operation 4), after delivering to a technical office PD (operation 2). At this stage, if the documents mismatch, freight wagon delays are possible due to breakdown of the route (X10). Additionally, there is the possibility of delays for other reasons (X13) – these are generally possible at any stage, but to simplify the model, a few possible scenarios (during arrival and departure operations) are considered. Possible delays (X10 and X13), are determined by statistical observations, the transition of TX-type could be set. These points apply to each of the fifteen stages of processing. It should be noted that Fig. 2 is a simplified representation and does not describe the whole technological process of the BTS operation, which consists of several blocks (in particular, operations X3, X9 and some others which may be performed in other blocks).

A functional simulation of the BTS operation may be conducted using the proposed model with regard to proposals on the processing technology optimisation. Comparison of the modelling results for the existing and proposed technologies may be carried out with the use of such criteria as the number of delayed freight wagons and the total duration of delays at the BTS. The best forecasting results which take into account unknown parameters could be achieved with the use of the fuzzy logic methods. Recent examples of the use of fuzzy methods for the optimisation of rail transport systems are presented in [20–22]. Simulations using Petri nets allow researchers to receive forecasting information on the operation of each of the BTS subsystems – a model built with the fuzzy logic tools provides further predictions and prevents the risks.

To assess risk and determine its effects, different rating systems can be used. In 2003, the World Customs Organisation developed a standardised risk assessment methodology [23]. In most cases, there is a common system of high, medium, and low risk – an alternative approach is the use of three types of corridors: green, yellow and red. Data relating to risk assessment must be applied taking into account the main factors influencing the implementation of

import and export operations in railway transport systems. The following key factors should be defined as the parameters affecting the passage of trains at BTS:

- ▶ country where from a consignment originates,
- ▶ type of cargo,
- ▶ type of train,
- ▶ invoice value of consignment,
- ▶ net weight of consignment.

In the frame of this study, on the basis of the conducted analysis of technological operations in the processing of goods within a full cycle of border operations, an algorithm of the execution of customs procedures at BTS which considers an operational risk has been developed. A flowchart of the procedure of customs control based on [24] is shown in Fig. 3.

The declarant or the owner of the goods submits a properly completed cargo customs declaration and shipping documents to the customs office. An electronic copy of the customs declaration is added to the customs database. Incoming information is analysed by the automated system in order to determine the level of risk that returns the final estimate. If no violations are found, the consignment is sent to the green zone and is passed without any delay. If the risk module of the information system shows that the potential risk is of low-level, the consignment enters the yellow zone, at an average level of risk – to the orange zone, and at a high level – to the red zone; these zones are characterised by a corresponding list of procedures.

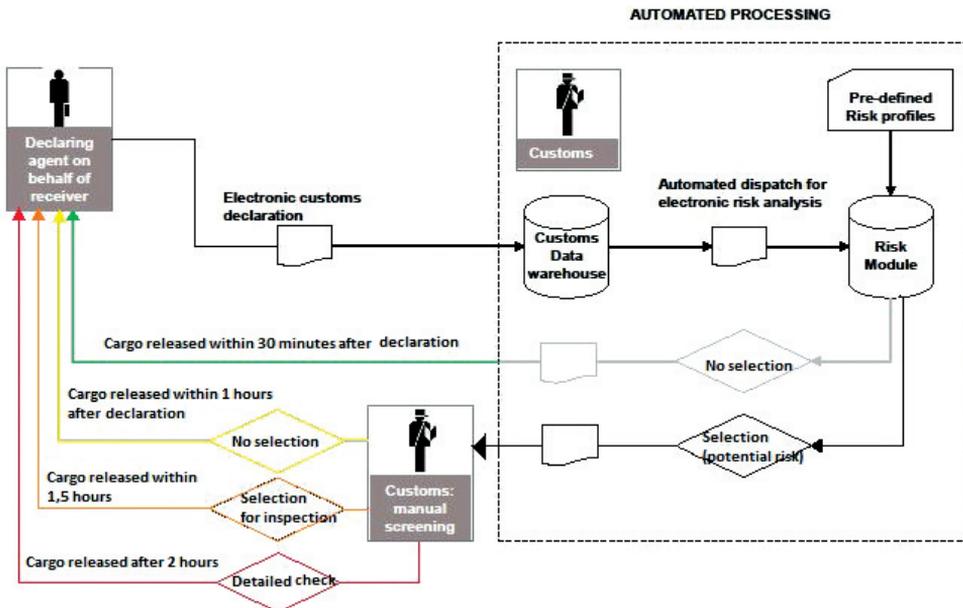


Fig. 3. Structure diagram of the customs control procedure based on the operation risk module

A correlation and regression analysis on the basis of the numerical results obtained from the described simulation model should be performed in order to determine the level of transport system reliability for the proposed risk management system. The use of these techniques allows us to assess the dependency of performance indicators and identify their mutual influence.

After analysing the impact of certain factors (cargo nomenclature, the country of origin and destination, the type of rolling stock, the invoice value of the goods, the net weight) on the delay values, a distribution of factors according to the conventional risk zones shown in Table 3 is performed.

Table 3. Conventional risk areas of the customs control process

Correlation coefficient	Displayed colour	Measures
1 ... 0,70	Red Zone	A high risk has been detected and a list of control operations has been formed. The implementation of measures requiring a detailed inspection of the consignment or vehicle is proposed
0,69 ... 0,50	Orange Zone	An average risk has been detected and a list of control operations has been formed. A documentary inspection and a check of some consignments or vehicles should be performed
0,49 ... 0,30	Yellow Zone	A low risk has been detected and a list of control operations has been formed. All forms of control should be provided for the documentary checks and other measures that do not require inspection of consignments or vehicles
0,29 ... 0,01	Green Zone	No risk has been detected; no checks of consignments are required

On the basis of the described model of risk analysis at BTS, a software program written in the Delphi language has been developed. The program user interface has text fields for inputting the main factors for the risk calculations and label fields for returning the calculated values of correlation coefficients, and the fields to display the risk assessment results.

With reference to Fig. 4a, when a consignment enters the red zone of risk, it is necessary to conduct a detailed check of the consignment or the train (Table 3); with reference to the yellow risk zone shown in Fig. 4b, the document checks and other measures that do not require the inspection of cargo or vehicles should be performed.

The set of indicators of the risk management system provides a precise algorithm for the processing of each consignment that, according to conducted forecasts, will reduce downtime at Ukrainian BTS by a factor of around 3.5. Further research and calculations have shown that the processing time of transit trains with a full cycle of border operations may be reduced by a minimum of 45 minutes to a maximum of 170 minutes, the duration of operations for transit trains may be reduced by a minimum of 35 minutes to a maximum of 120 minutes, and the duration of train maintenance – from 75 to 180 minutes.

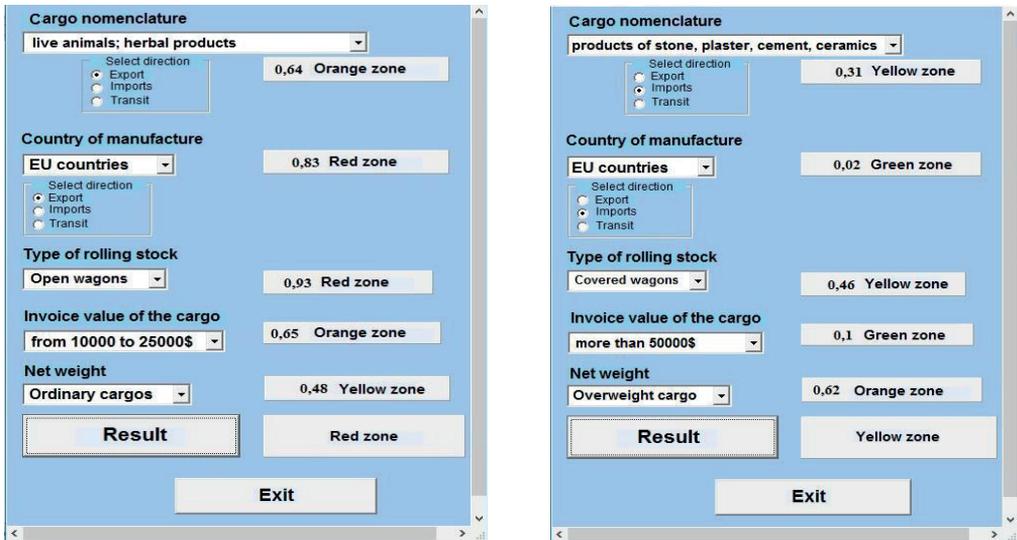


Fig. 4. Interface of software for assessing the level of risk at BTS: a) red zone, b) yellow zone

#### 4. Conclusions

The conducted analysis of the Ukrainian BTS operation allowed us to determine the main reasons for the delaying of rail freight wagons. The performed literature analysis has shown that in many works, no attention has been paid to the problem of optimising the border and customs operations in order to reduce downtime at BTS. To optimise the transmission system of freight traffic at BTS, a simulation model of the interaction process at stations has been developed and the use of a risk management system has been proposed. The approach for the risk assessment of rail freight wagon delays that takes into account the key factors influencing the passage of trains through BTS has been developed; on this basis, an algorithm for developing customs procedures for BTS based on an operation risk module has been proposed.

To determine the level of the transport system reliability for goods admission with regard to international traffic, simulation models based on the Petri nets have been built. The integration of a correlation and regression analysis method into the decision support system in the risk management system has been introduced. The list of appropriate specific measures for processing the consignments at BTS has been provided.

The implementation of the analysis and risk management systems would help Ukrainian border stations create suitable conditions for transport operators, improve the efficiency of technological procedures, reduce the downtime of rail freight wagons at BTS; together, these would facilitate the further integration of Ukrainian railway transport into the European transport system.

## References

- [1] Mironenko, K.P., *Study the operation conditions of border transfer points in processing of wide nomenclature of import cargoes*, Kharkiv 1975.
- [2] European Agreement on Important International Combined Transport Lines and Related Installations, United Nations Economic Commissions for Europe Inland Transport Committee, Geneva, 1991.
- [3] The concept and the program of restructuring of railway transport of Ukraine, Ministry of transport, 1998.
- [4] Kirpa G.N., *A new level of economic cooperation in the field of international transport business*, Railway transport of Ukraine, vol. 3, 2002, pp. 2-8.
- [5] Kirpa G.N., *Integration of railway transport of Ukraine into the European transport system*, Dnepropetrovsk National University of Railway Transport, 2004.
- [6] Drożdźiel P., Buková B., Brumerčíková E., *Prospects of international freight transport in the East-West direction*, Transport Problems, vol. 10(4), 2015, pp. 5-13.
- [7] Abramović B., Zitrický V., Biškup V., *Organisation of railway freight transport: case study CIM/SMGS between Slovakia and Ukraine*, European Transport Research Review, vol. 8(4), art. no. 27, 2016.
- [8] Cauty M., *Utilisation d'une liaison telematique pour gerer la circulation entre deux gares frontier*, Revue Generale des Chemins de Fer, vol. 106(1), 1987, pp. 25-29.
- [9] Ferreira L., Sigut J., *Measuring the performance of intermodal freight terminals*, Transportation Planning and Technology, vol. 17, 1993, pp. 269-280.
- [10] Li X., Xie R., *Analyses of freight forward-time in railway transportation*, Proceedings of the Conference on Traffic and Transportation Studies, ICTTS, 2000, pp. 198-201.
- [11] Jarašūnienė A., *The solution of customs posts management problems at railway border stations*, Transport, vol. 18(3), 2003, pp. 108-113.
- [12] Alyoshinskiy E.S., *Basis for the formation of the international rail freight transport*, Thesis, Ukrainian State Academy of Railway Transport, 2009.
- [13] Kihiteva J.V., *Improvement functioning of the information subsystem for border transfer stations*, Thesis, Ukrainian State Academy of Railway Transport, 2010.
- [14] Wan L., Guo Y.C., Wei Y.Y., *Shanghai west railway station's design based on communication space and ecological integration*, Applied Mechanics and Materials, vol. 584-586, 2014, pp. 439-442.
- [15] Zitrický V., Černá L., Abramović B., *The proposal for the allocation of capacity for international railway transport*, Procedia Engineering, vol. 192, 2017, pp. 994-999.
- [16] Aleshinskiy E., Naumov V., Prymachenko G., *Using the Petri nets to form technological lines of the passenger trains in Ukraine*, Archives of Transport, vol. 38(2), 2016, pp. 7-15.
- [17] Zhang Y., Zhang H., Wang H., *Security analysis on railway network time protocol based on colored Petri nets*, Journal of the China Railway Society, vol. 39(10), 2017, pp. 82-88.
- [18] Lan L., Zhang Y., *Vulnerability analysis of railway time synchronization network protocol based on stochastic Petri net*, Journal of the China Railway Society, vol. 39(8), 2017, pp. 85-92.

- [19] Yianni P.C., Rama D., Neves L.C., Andrews J.D., Castlo D., *A Petri-Net-based modelling approach to railway bridge asset management*, Structure and Infrastructure Engineering, vol. 13(2), 2017, pp. 287-297.
- [20] Menéndez M., Martínez C., Sanz G., Benitez J.M., *Development of a Smart Framework Based on Knowledge to Support Infrastructure Maintenance Decisions in Railway Corridors*, Transportation Research Procedia, vol. 14, 2016, pp. 1987-1995.
- [21] Zhang J., *Analysis on line capacity usage for China high speed railway with optimization approach*, Transportation Research Part A: Policy and Practice, vol. 77, 2015, pp. 336-349.
- [22] Pattanaik L.N., Yadav G., *Decision support model for automated railway level crossing system using fuzzy logic control*, Procedia Computer Science, vol. 48(C), 2015, pp. 73-76.
- [23] Guidance document on customs formalities on entry and import into the European Union, Brussels 2016, 40.
- [24] Stengel D., *From full stop on the border to selective customs control*, First Seminar on Multimodal Transport and Logistics. Kyiv, 4-5 June 2013.