Designing a Petri Net Model to Organize the Transport of Goods in the European Rail Chain

Nermin Čabrić [1], Ratko Đuričić [2], Vladimir Malčić [2], Željko Stević [2]

[1] University of Sarajevo, Faculty of Transport and Communications, Zmaja od Bosne 8, 71000 Sarajevo, Bosnia and Herzegovina;
nermin.cabric@fsk.unsa.ba

[2] University of East Sarajevo, Faculty of Transport and Traffic Engineering Doboj, Vojvode Mišića 52, 74000 Doboj, Bosnia and Herzegovina;
ratko.djuricic@sf.ues.rs.ba, vladimir.malcic@sf.ues.rs.ba,
zeljko.stevic@sf.ues.rs.ba

Abstract: A new railway concept where there is more than one company participating in the transportation chain, Lead Railway Undertaking – LRU, should be in charge of managing and controlling the transportation chain. Using a timed Petri net – TPN, a model of organizing European railway transport will be introduced as a system with discreet events whose state depends on the occurrence of discreet events from the moment of ordering the transportation until the moment of delivering the goods to the client. The tracking of wagons/goods is presented with a token that moves through a designed petri organization model. With the example of a possibility of shortening the estimated time of the wagon retention in stations by shortening the time of commercial checkups of goods, the PN model portrays a strong diagram of all the operations that include wagons, as well as the processes that occur parallel and in sync all along the railway chain.

Keywords: TSI TAF; Petri net; European railway; ITUs

1 Introduction

An intelligent technological information system enables continuity in cross-border data transmission. Data transmissions through the European Railway System is the key element to assure the quality service provision in the international railway. Today, railway companies of all sizes face the need for control and integration of operative information. The most thriving technology for operative information control is creating a mass net of all the participating parties in the transportation chain from the user to the supplier of the transportation service. The network infrastructure is developed on a global level, and it allows the connection of physical and virtual devices using interoperable communication protocols and intelligent interfaces. In order to achieve an economically acceptable, reliable and safe process, an efficient operative data transmission is implemented using an established technical frame through the technical specification of interoperability, which refers to the element of a "loaded traffic application" of the subsystem of a "telematics application", and belongs to the functional area of Appendix II of the Directive (EU) 2017/797 (Technical Specification for Interoperability relating to Telematics Applications for Freight Services – TSI TAF). The main goal of this research is organizing the transport of goods in the European railway chain using Petri nets. The created model enables the leading railway carrier to provide the user of railway transportation all of the necessary information, especially: route information; Information about train schedule for arranged points of reporting, including starting point, point of exchange/handover and destination of arranged transport; Predicted time of arrival to final destination, rated stations and intermodal terminals; Traffic interruptions (when the leading railway carrier learns of traffic interruption, it timely informs the service user). The aims and contributions can be manifested through the following. The developed model allows the leading railway carrier the following: To be more efficient in defining a transportation service by stating the price of service and time needed for its implementation, as well as determining the availability of wagons depending on a type of goods that is to be transported; To have precise and timely information about the position on the railway network and predicted arrival of wagons and intermodal freight units, as well as place of loading of empty wagons; To deliver a complete service in a reliable and consistent manner by using common business processes and related information systems to all interested parties (infrastructure managers, service users, customs, etc.) who must have computers for data exchange; To assess the quality of implemented service based on defined values. A primary motive for writing this paper is a current insufficient correlation between all participants in a railway transport supply chain, especially between the railway carrier, infrastructure manager and users of transportation service. This paper also contributes to better wagon management.

2 Related Papers

The Petri Net (PN) model is used in different fields. Harifi et Nakjavanlo [1] use PN as a support system for directing and managing police cars. Cavone et al. [2] have used PN for intelligent, safe and ecologically acceptable management of transport systems by using intelligent transport systems that combine innovative technologies and transportation frames with a goal of finding appropriate solutions for all transportation problems. While providing a service "Car-sharing", Clemente et al. [3], contrary to the prevailing approach, propose a methodology for determining an optimal threshold that explicitly considers stochastic buyer reactions on stimulating the use of such service. It is presented a support system for deciding on solving problems of relocating vehicles based on an economic incentive of the service user. Fanti and Ukovich [4] have examined the existence of great need for integrating and coordination of previously autonomous elements and systems in order to reach a mutual goal that otherwise is not achievable. It has been formalized a structural and combined frame for support of decision makers through the implementation of integrated systems of larger scale that are heterogeneous and work independently, but are networked together for the sake of achieving a mutual goal. Sohag and Yiannis [5], in their paper, present a summary of Bayes nets (BN) and PN application in an analysis of system security, assessment of reliability and risk. This paper emphasizes a potential use of approaches based on BN and PN in relation to other classical approaches, and their relative strength and weaknesses in different practical application scenarios. The paper [6] presents a general approach to modeling intermodal terminals in a chain of goods transportation. The model presented allows the assessment of operational performances of intermodal transport system, assessment of efficiency level of intermodal terminal and identification of "bottle-neck" based on appropriate system performance indicators. This model is done by implementation of Timed Petri Nets (TPN) where places are resources, capacities or conditions while crossings represent flow and activities in the terminal. Tokens represent intermodal freight units or means for transporting freight units. Transport of goods is converted from one form to intermodal transport where goods are loaded into an intermodal freight unit, which allows a more flexible, reliable and sustainable transportation service. Besides modeling an intermodal transport system, PN are a great tool for analyzing logistic systems [7]. Even though it is not possible to show operation complexity in an intermodal transportation chain, their graphic aspects provide certain advantages for graphic presentations and model inspections. In [8], it is proposed a procedure of meta-modeling that gives a reference model used by decision makers while assessing performances of intermodal transport network. In order to obtain a generic model that describes a non-specific, from the point of its structure and behavior, intermodal transport network, it is used a Meta approach, actually, modeling from top to bottom and procedures of modeling. The model is presented in a standard language for a visual presentation, Unified Modelling Language – UML, that uses a graphic and textual method of presenting structural and dynamic system behavior. Kabashkin [9] has developed the Decision Support System (DSS) for the selection of alternative directions in a large traffic system that includes a heuristic approach and integration of simulation. The practical implementation of DSS simulation based on the PN model has been proposed. In their paper, Bao et al. [10] propose a hybrid ELM-PS method for predicting train delays that not only gives enough time to make additional decisions but it also has practical importance for improvement of information quality delivered to railway workers and assistance for passengers in estimation of travel time duration. Khakdaman et al. [11], in their paper, have explored the readiness of sender to delegate the selection of transportation mode by using an analysis of discrete transport. The results show that, under certain conditions, most of senders are willing to authorize the selection of transportation to the service provider. Cooperation and connection of all participants in transportation of goods by railway network is very important and it is established through a TSI TAF platform. Our work through the application of PN has found efficient solutions for directing railway wagons to loading places, actually it efficiently and operatively manages carts. The importance of this cooperation in the ever-growing market of road transportation has been presented in paper [12]. The main challenge of PN use is reasonable model construction that demands certain skills. More and more, it is used for security, reliability and risk assessment in the system. TSI TAF as a functional sub-system of railway network directly affects the reliability of railway system and therefore, indirectly, its safety.

3 TAF TSI Description and Characteristics

TSI TAF sets mandatory functional and technical specifications for data exchange in a harmonized format between Infrastructure Managers (IMs), railway Undertakings (RUs) and other participants. For creating a chain of trains, it is necessary that RU has data about: Limitations of railway infrastructure; Technical data on wagons (Rolling Stock Reference Database – RSRD); Dangerous goods – RID materials that are found in a reference database; Updated wagon information status; Operational database implemented by RUs, IMs, Wagon Keepers and users of transportation services. Besides data exchange, TSI TAF describes an operational process that involves IMs and RUs. Therefore, TSI TAF has a great impact on existing business processes of railway infrastructure. TSI TAF, or at least an information interface with other partners, must be implemented in a similar way by all users of TSI TAF, including IMs and RUs. TSI TAF functions define data processing in regard to following variables: When (at what moment)? What (which information and content) should be sent? Who (partner or partners)? How (in which format) data must be exchanged? The purpose of TSI TAF is to ensure an efficient data exchange by determining technical frameworks in order to maintain a process of transportation in an acceptable price range. It encompasses applications in providing transportation services of railway undertakings in freight transportation and management of connections/chains with other forms of transportation in a continuous intermodal transportation chain. TSI TAF has an influence on conditions under which users use railway transport.

3.1 Architecture of Data Exchange

Data exchange is done through “Peer to Peer - P2P”. This is the model of data exchange where every entity of network is a client and a server. In informatics, it means a concept of networking computers without a server, where every computer is an intelligent work station that finds other computers over an Ethernet package as the most commonly used technology for local networks and it communicates with them directly, without needed authorization on a central server. Communication P2P through IP networks between IMs and RUs, as well as with other users through a central database and individual databases, is established with a common interface (CI). The architecture of data exchange is developed in such a way that databases of wagon keepers (WK), RUs, IMs, station managers (SM), rolling stocks and users of transportation services are mutually connected through communication processes and protocols. The intelligent railway system can be defined as a modern city that functions in an intelligent and sustainable way in order to ensure its sustainability and efficiency. This goal can be reached by integrating diverse infrastructure and services into joint units, so the intelligent devices can monitor and control them.

3.2 TSI TAF Process

The process of planning begins with loading the wagons, maneuvering and setting up the loaded wagons on the tracks ready for shipment. If the railway chain includes more than one carrier in railway traffic, then that becomes the leading railway carrier (Lead Railway Undertaking - LRU) which is accountable to organize and control the transport line. The user sends a bill of lading to the leading railway carrier. The bill of lading must contain all of the needed data about the transport of goods (Contract of International Carriage of Goods by Rail – CIM), unique rules of the contract for the usage of carriages in international railway traffic (Uniform Rules concerning Contracts of Use of Vehicles in International Rail Traffic – CUV) and valid national rules. According to the contract, LRU provides the user of the transportation services information about: The route; The movement of trains on pre-set locations on the wagon trip plan, including at least the beginning point, the trade/handover point and the endpoint of the contracted transport; Estimated Time of Arrival (ETA) to the end destination, including shunting stations and intermodal terminals. In freight transport, the work of LRU considering shipments begins when the user gets the bill of lading. Every railway undertaker (RU/LRU), which participates in the transport is obligated, based on the contract with IM, to insure the train route and control the movement of the train on its section of the trip. Train routes can be either bigger already reserved routes or an ad hoc train route can be requested from IM. Based on data transmission between IMs and RUs the departure time or arrival time of a wagon to a specific location or if it in a transport chain the responsibility moved from one RU to the other. The TSI TAF process consists of a planning phase as well as an operative (executive) phase. The operative phase of the organization process of European railway transport begins with forming a train composition that is a wagon placement in the train structure according to the referral order provided by the train forming plan. Using the train forming plan, wagon flows are being organized in single-group or multi-group freight trains. Single-group trains do not need any kind of changes to their composition on the whole traffic route. Multi-group trains are formed by two or more groups of wagons which are all arranged for themselves according to the stations they are headed.

4 Petri Net Design

Petri Nets (PN) portray an immediate and strong diagram of all needed operations, shared resources as well as processes which are taking a place in a parallel manner and in synchronization. PN as a graphical-mathematical tool is suitable for modeling and shaping various types of dynamical, discreet and distributive systems. The changes occur in a limited number of steps in an observed time space; A distributive system consists of a certain amount of autonomous subsystems, which are inter-twined and share resources when performing some specific tasks. Those subsystems are often physically arranged. TPN is used for the evaluation of system performances, and Colored Petri Nets (CPN) [13] are useful for modeling complex systems which perform a few different tasks because they allow the use of more mutually different tokens. Models with discreet events are often used to describe decision making and operative processes in logistical systems [14]. Even if PN are not able to portray in detail the complexity of planning phase and executive phase in the system of organization of the European railway transport, the use of TSI TAF as simulation tools have certain advantages. Their graphical aspect enables them to concisely and effectively project (design) and check the model, while the mathematical presentation enables a simple simulation which takes into consideration dynamic conditions and changes in the system, like the movement of shipment, i.e. the movement of wagons or Intermodal transport units – ITU from the place of loading to the end destination. In this section, a frame of PN organization of the transport of goods in the European railway chain of traffic is recommended. In the recommended frame, places represent resources and capacities or conditions and activities on the terminal, and tokens are ITUs or means of transportation of ITUs. The recommended frame of PN organization of the transport of goods in the European railway chain of traffic uses a modular approach and it is made of submodules. The main submodules which make the recommended frame of PN organization of the transport of goods is: unloading the train; coming and going of ITUs; realization of train route request function; realization of train preparation function; realization of train ride functions.

4.1 Functions of Reference Files

IMs, RUs, logistic service providers and rolling stock managers must have access to assortment of reference files: types of dangerous goods, IM, RU and service provider codes; codes of transport service user, so the freight trains on the European railway net can be exploited. Databases which will implement RUs, IMs, wagon owners or clients are: RSRD - Rolling Stock Reference Databases; WIMO – Wagon and Intermodal Operational Unit Database; Train Route Database; Reference files which are: Kept and administrated centrally (Coding for all IMs, RUs, service providing companies; Coding clients for freight transport); Kept and administrated locally (reference files of emergency services, connected with dangerous goods data). Data found in reference files and databases must represent the real state in any moment. In order to enable tracking of moving trains and wagons, data in operative databases for wagons and intermodal units must be updated at every relevant event in real-time.

4.2 Realization of the Train Path Request Function

Train routes define wanted, accepted and real data which need to be stored in databases. Routes determine exploitation and technical train characteristics for every section of the route. Based on the train list, IM has information about the real composition. RU must deliver IM all of the needed data about when and where the train must ride as well as technical characteristics to the extent in which they are connected with the railway infrastructure. If more RUs participate in transport, then it is selected an LRU that will communicate with IM. The Route requested by LRU can be accepted or declined by IM. In the case of declining the route request, IM gives details about the reasons of declining the route which are updated. If the request is accepted, then IM gives LRU details about the train route. When LRU confirms the IM train route, it goes into the next submodel and realization of train preparation function phase. The submodel "Realization of the Train Path Request Function" of the proposed PN design framework for the organization of the transport of goods in the European railway chain is given in Figure 1.

4.3 Realization of the Train Preparation Function

In order for the LRU/RU to give the notice to IM about the train composition, it is necessary that it possesses data about: Infrastructure limitations; Technical data about wagons (RSRD database); Data from the RID reference file; Updating wagon status (WIMO). Train preparations begin with an IM notice about the LRU train composition. In preparation phase, checkups are done in certain databases containing infrastructure limitations, technical and exploitation characteristics of wagons and intermodal freight units. After all, an LRU checkup notice is sent to IM that the train is ready to go. The submodel "Train Preparation Function" of the proposed PN design framework for the organization of the transport of goods in the European railway chain is given in Figure 1.

4.4 Realization of the Train Running Function

With the arrival of the composition on the shipping track, a dialogue is started between IM and RU to insure the exchange of data about the train and its estimated time of travel on the net. IM gives RU and the neighboring IM information regarding the estimated time of departure and the time of arrival to the location of transition to the net of the next IM.

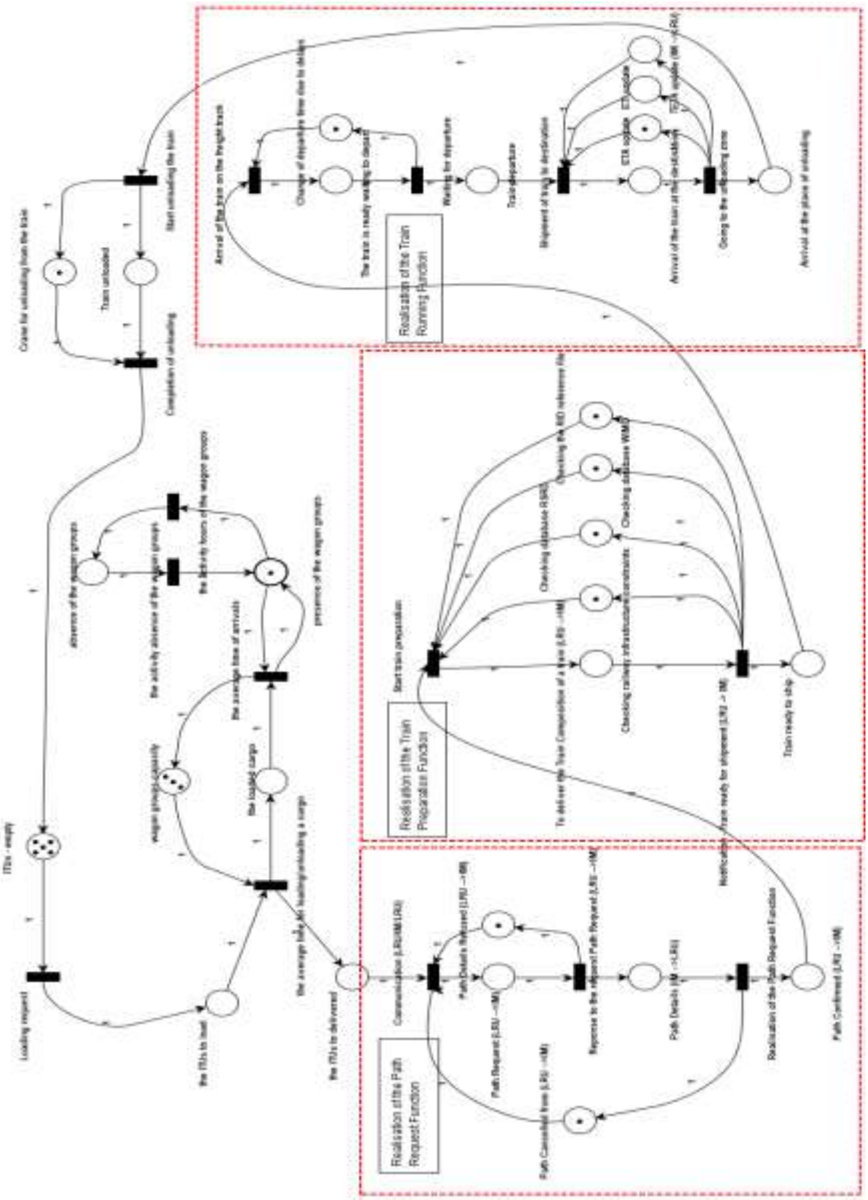

Figure 1

PN design model of the organization of goods transport in the European railway transport chain

Data considering train traffic enables the estimated times of arrival on the observed points agreed upon in the contract of transport, and therefore the relative positon of train during the trip to be known. In the contract, the locations of train running briefing are determined. This data exchange happens between IM and the RU which reserved the route the train rides on. The individual supervision of wagons and intermodal freight units is performed in the communication between RUs which participate in the transport chain and LRU. According to the contractual agreement, LRU will insure the user with the ETA – Estimated Time of Arrival and ETI – Estimated Time of Interchange of wagons from one RU to another on the shipment level. For intermodal freight units which are loaded on the wagons, the ETI of the wagon is also the ETI of the intermodal freight unit. In terms of ETA of intermodal freight units, RU cannot calculate the ETA for different types of transport which participate in the continuous transport chain except the railway part. RU can only deliver to the user of the transport service the ETI of the exchange of intermodal freight units in intermodal terminals where they change the means of transport. The submodel "Train Running Function" of the proposed PN design framework for the organization of the transport of goods in the European railway chain is given in Figure 1.

5 Simulation

In the PN model of organization of transport of goods in the European railway traffic chain, we can model the influence of time needed for data exchange, process and protocols that unwinds through databases which are implemented by RUs, IMs, Wagon Keepers and users of transport services at the time of the delivery of intermodal freight unit *t* to the end user. Reliable and good quality information shortens the time needed for the technical-commercial checkup of the train which shortens the retention time as well as an earlier time of arrival to the end destination. After the arrival of the train at the end destination, a commercial shipment checkup is done, the receiver is briefed about the shipment delivery and the train is set on a specific place to unload. The receiver is briefed by means of TSI TAF directly about the movement and delivery of shipment.

5.1 Software Tools for Performance Evaluation

For the simulation model of a fictive supply chain problem, the software tool TimeNET 4.3. was used and thereat two new types of tokens were defined. A “Workpiece” token type represents parts, which need to be transported in containers and the “Container” token represents an empty container, which is returned to the receiver to reload after delivery and unloading. The main model contains two submodels “TransportToPlan” and “TransportToSupplier”. In examples of stochastic CPN done by the TimeNet software, there is an example of a chain of supply between the supplier and user and the transport takes place on the railway. For the analysis of the influence of time needed for a commercial-technical checkup at the time of inactivity of the factory, in the existing TimeNet supply chain model, an “Inspection“ submodel is included (Figure 2).

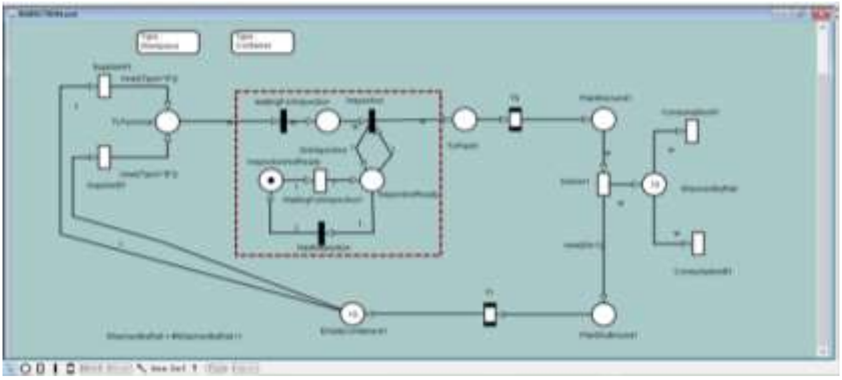

Figure 2
A supply chain model with a commercial vehicle checkup submodel

In the submodel in Figure 2 in the "OnInspection" point, the intermodal freight unit receives its commercial-technical checkup and the needed time is modeled with a transition spot "WaitingForInspection" where we can see the influence of time in a period of factory inactivity by changing the checkup retention time length. ShipmentByRail parameters which define a system of intermodal transport supply chain in the TimeNet software for the submodel of commercial checkups aside from the already given ones for the "Supply Chain" example are as follows:

Places		**Tokens**		
Place name	Token type			
OnInspection	Workpieces	Token type	Attribute	Data type
InspectionNotReady	integer	Workpiece	Type	string
InspectionReady	integer	Container	N	integer

Transition			
Transition name	Transition type	Time function	
Inspection	immediate		
WaitingForInspection	immediate		
WaitingForInspection1	timed	Det(0.90)	
NextInspection	immediate		#OnInspection==0 && #ToTerminal1==1 (glob.)

Changing certain parameters like: container retention time on a commercial-technical checkup, train departure timetable or the number of empty containers, we can simulate the influence of the commercial-technical checkup on the total delivery time in the supply chain. In the existing model of the supply chain made with the use of PN with the TimeNET software, if we execute the commercial-technical checkup using the "Inspection" submodel, we can analyze the influence of the time needed for the commercial-technical checkup on the time where the "ShipmentByRail" does not have a token which represents the delivered goods.

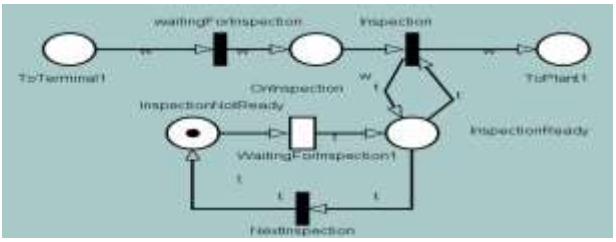

Figure 3
Submodel of a commercial train checkup in a supply chain

5.2 Results and Discussion

Simulations done in the TimeNET software for a hypothetical example of a supply chain show that the average time when the "ShipmentByRail" does not have a token, measured with the expression (#ShipmentByRail<1), can be reduced in the following ways: Shortening the interval of freight containers shipments by train, Shortening the time of commercial-technical checkup execution. Shortening the interval of shipment of loaded containers by train influences a change of the predefined train timetable, but shipment is possible through ad hoc routes, which has been found to be a very expensive option, so shortening the time needed for commercial-technical checkup is the remaining option. Assume that the manufacturer and the consumer improve their work processes and that the manufacturer of goods needs empty containers returned as quickly as possible for a new loading and that the consumer needs a more frequent shipment delivery. This can be achieved by shortening the container trading time. Applying the PN software "TimeNET", first of all, we model the case where the time of the presence of the "OnInspection" token, which represents the time length of the commercial-technical checkup, amounts to one hour and that is the case where there is an electronic bill of lading and TSI TAF is not implemented with the following parameters: The number of containers, C=10; Crossing time interval "WaitingForInspection", $T_{inspection}$=1 hour: Crossing time interval "WaitingForTrain", T=100 hours.

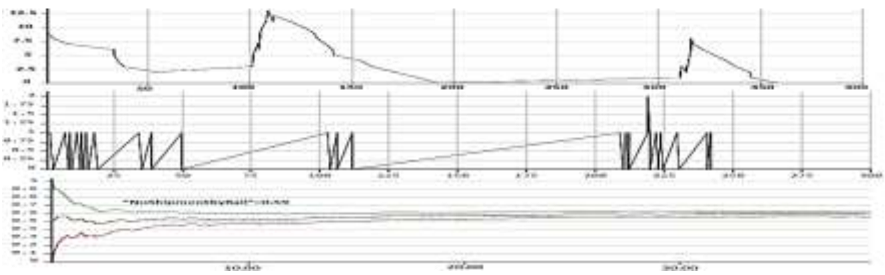

Figure 4
Company inactivity for C= 10, $T_{inspection}$ = 1 hour, T = 100 hours (case example)

Figure 4 is a graph of results in positions “ShipmentbyRail” and “OnInspection” and also as an average time value of “NoShipmentbyRail”=0.59 when in position “ShipmentbyRail” there were no tokens, actually, when wagons from containers did not come and there were no delivery of goods. As an enhanced system, we are modeling the case when token time spent in position “OnInspection” that represents the time of commercial-technical checkup is 0.17 hours, actually when it is in use an electronic shipment document, and TSI TAF is implemented with the following values: Number of containers, C=10; Time interval “WaitingforInspection”, $T_{inspection}$=0.17 hours; Time interval “WaitingforTrain”, T=100 hours.

Figure 5 represents a graph for given values and it shows the results for tokens being in positions of “ShipmentbyRail” and “OnInspection” as an average value of time “NoShipmentbyRail”=0.55 when in position of “ShipmentbyRail” there was no token.

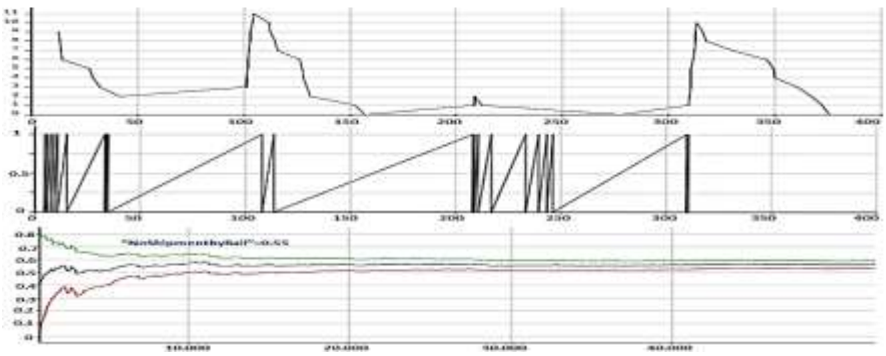

Figure 5
Inactivity of company for C= 10,$T_{inspection}$ = 0,17 hours, T = 100 hours (case example)

Both graphs show periods when there are no railway container deliveries to the private railway tracks of private transport service users and when the manufacturer has no goods for production, which can create time periods when company does not operate. Possible solutions for improvement are shortening a time interval of train commuting, shortening switching wagons time and shortening the time of commercial-technical checkup execution. Simulations done in the program TimeNET for a supply chain shows that average time when there is no railway cart container delivery, actually average time of company inactivity measured by token (#ShipmentbyRail<1), can be shortened. Average time when there is no token in position “NoShipmentbyRail”, actually when there is no delivery of goods to the company, can be decreased from the value of “NoShipmentbyRail”=0.59 to “NoShipmentbyRail”=0.55 by efficient data exchange between IMs, RUs, sender receiver and all other participants in a transportation chain. Improvement of financial validity and reliability of transport is contributed by TSI TAF. Bosnia and Herzegovina do not have a liberal market on which international operators can work, so this can be one of the limitations of this study. However, this problem should be solved soon because our country is in a process of market liberalization.

Conclusions

This paper presents the organizational characteristics of transportation of goods in a transportation chain of supply including railway transport. The complex organization of railway transportation in the European railway network and possibility of operational monitoring of the wagons is modeled with Petri nets. The purpose of the model is to describe a discreet system of events as the European railway system of good transportation is. For getting realistic results of the proposed basic model, it is necessary to set realistic railway environment with all data related to wagons and intermodal freight units from the moment of forming a composition to the moment of its arrival to the place of unloading. The proposed model, by using the logic of PN, describes a system of organization and movement of wagons on the European railway network as a system with more discreet events. The communication between RUs and IMs is improved in terms of quality of providing transport services and in terms of accuracy of the estimated arrival time. In this paper, we decided to use PN to acquire a model which would in detail present the system and, from the computer aspect, the diagrams are convenient for tracking the system and measuring its efficiency. The model is modular and can be easily expended to take into consideration other processes in the continuous intermodal transport chain of supply. The model can also be used for developing the simulation platform for the control of system operations, as well as discovering and preventing dangerous states. With the growing industrial development and population, the role of railways in transportation is going to be crucial in upcoming years [15]. So, in further research, the proposed model should be developed and tested in a real environment

References

[1] Harifi, S., Nakhjavanlo, B. B., Decision support system based on petri net for a police vehicle command and control system. In Artificial Intelligence and Pattern Recognition (AIPR), International Conference on, pp. 64-69, IEEE, 2016

[2] Cavone, G., Dotoli, M., Seatzu, C. A Survey on Petri Net Models for Freight Logistics and Transportation Systems. IEEE Transactions on Intelligent Transportation Systems. pp. 1-19, 2017

[3] Clemente, M., Fanti, M., P., Iacobellis, G., Nolich, M., Ukovich, W., A Decision Support System for User-Based Vehicle Relocation in Car Sharing Systems. IEEE Transactions on Systems, Man, and Cybernetics: Systems. PP. 1-14. 10.1109/TSMC.2017.2665881. 2017

[4] Fanti, M., P., Ukovich, W., Decision Support Systems and Integrated Platforms: New Approaches for Managing Systems of Systems. IEEE Systems, Man, and Cybernetics Magazine. 3. 18-22, 2017

[5] Sohag, K., & Yiannis, P., Applications of Bayesian networks and Petri nets in safety, reliability, and risk assessments: A review. Safety Science. 115. 154-175, 10.1016/j.ssci.2019.02.009, 2019

[6] Dotoli, M., Epicoco, N., Falagario, M., Cavone G., A Timed Petri Nets Model for Intermodal Freight Transport Terminals. IFAC Proceedings Volumes Volume 47, Issue 2, 2014, Pages 176-181, 2014

[7] Labadi, K., Chen, H., Modelling, analysis and optimisation of supply chains by using Petri net models: The state-of-the-art. IJBPSCM. 2. 188-215, 10.1504/IJBPSCM.2010.036199. 2010

[8] Boschian, V., Dotoli, M, Fanti, M.P., Iacobellis, G. Ukovich, W., A Metamodelling Approach to the Management of Intermodal Transportation Networks. IEEE Transactions on Automation Science and Engineering, Vol. 8, 457-469, ISSN: 1545-5955, 2011

[9] Kabashkin, I., Heuristic Based Decision Support System for Choice of Alternative Routes in the Large-Scale Transportation Transit System on the Base of Petri Net Model. Procedia Engineering. Volume 134, 2016, Pages 359-364, ISSN 1877-7058. 2016

[10] Bao, X., Li, Y., Li, J., Shi, R., Ding, X., Prediction of Train Arrival Delay Using Hybrid ELM-PSO Approach. Journal of Advanced Transportation. 1-15, 10.1155/2021/7763126, 2021

[11] Khakdaman, M., Rezaei, J., Tavasszy, L. A., Shippers' willingness to delegate modal control in freight transportation, Transportation Research Part E: Logistics and Transportation Review, Volume 141, 102027. 2020

[12] Los, J., Schulte, F., Spaan, M. T. J., Negenborn, R. R., The value of information sharing for platform-based collaborative vehicle routing, Transportation Research Part E: Logistics and Transportation Review, Volume 141, 2020, 102011, ISSN 1366-5545. 2020

[13] Kurt, J., Coloured Petri Nets. a Way to Describe and Analyse Real-World Systems-Without Drowning in Unnecessary Details. 395-401, 1987

[14] Dotoli, M., Fanti, M. P., Mangini, A. M., Stecco, G. Ukovich, W., The impact of ICT on intermodal transportation systems: a modelling approach by Petri nets. Control Engineering Practice, 18 (8), 893-903, 2010

[15] Banić, M., Miltenović, A., Pavlović, M., & Ćirić, I. (2019) Intelligent machine vision based railway infrastructure inspection and monitoring using UAV. Facta Universitatis, Series: Mechanical Engineering, 17(3), 357-364