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MODEL FOR DIMENSIONING TECHNOLOGY AND CAPACITY OF BORDER RAILWAY STATIONS

ABSTRACT

The participation of the national rail networks in the European corridors requires certain modifications and their redefinition. Because the railway stations are special parts of the railway networks, they should be modernized, especially in south-eastern Europe. The main issue in the process of construction or reconstruction of railway stations is dimensioning (projection) of infrastructure facilities. The dimensioning of the infrastructure capacity is in direct correlation with the projected technology of work and the planned volume of traffic. This paper presents the simulation model which allows sizing facilities of border rail stations on the basis of the defined work and traffic technology.

KEY WORDS

modelling, simulation, capacity, technology, border railway station

1. INTRODUCTION

Optimizing the use of railway infrastructure is a complex and difficult task. The capacities of one railway station, in specified time period and terms, enable receipt, processing and dispatch trains. Defining capacity is needed to define the timetables, the traffic organization and technological processes, their optimization, planning of investments etc. The basic problem which arises is how to dimension capacities, so the train service can be carried out without problems. Accordingly, it is necessary to have in mind that infrastructural facilities and resources are extraordinarily expensive, as at the building and procurement point as well as the maintaining point. And the costs of labour are notable, too.

This means that their improper dimensioning can affect the railway profitability because railway capacity is not static, and it is extremely dependent on the way of use.

In literature there are many methods and models for dimensioning of railway capacity.

The International Union of Railways (UIC) proposed the UIC method which calculates the capacity in line sections to identify bottlenecks. It takes into account the order of trains, and a buffer time is inserted to achieve an acceptable quality of service. This method was officially dropped some years ago and is no longer recognized as a standard. It has been superseded by more general recommendations that establish a link between railway capacity and railway quality [1]. In their last recommendation, the International Union of Railways presented the compaction method (UIC 406 method) as the best way of performing a capacity study. The capacity calculation is based on the compression of timetable graphs on a defined line or line section.

The paper [1] provides an overview on the main concepts and methods for capacity analysis, and presents an automated tool that is able to perform several capacity analyses. These analyses are related to certain determination of capacity of certain railroad sections but not for facilities of railway stations.

In work [2] for traffic congestion controls, queue thresholds are used. For the queuing theory the system GE/GE/1/N approximation is used, which has been developed to study the spread of traffic congestion in complex networks. Then, for modelling the spread of traffic congestion in complex rail networks in [3] a Weight-evolving traffic network model is used, which is based on Barrat–Barthelemy–Vespignani (BBV) model. This paper simulates and analyzes the process of the emergence and spreading of congestion, which is triggered by adjusting of data generating speed and data sending ability of the network.

The railway traffic management is presented in paper [4], in which new extended equation for train traffic is presented, altogether with its impact on the length of the braking distance when several trains are in traffic. For this purpose, numerical and simulation analyses are performed.

The technology and railway station capacity modelling are presented in the following works [5], [6], [7] and [8]. Work [5] presents a simulation model for technology and capacities optimization for interim stations (transit stations) with usage of the Non-Markovian systems queuing theory. To simulate railway traffic at the stations (into the railway transit stations), in [8] *Cellular Automata* is used, and in [6] *hybrid Petri nets-based simulation model* is used. In work [7] the marshalling yard station model is presented, where the station optimization is the main issue and it is based on the simulation modelling of the technological operations such as train formation and unformation. The analytical modelling of the technological operations in the marshalling yards is made in work [9].

The simulation modelling for other types of traffic is applied for operations management at container terminals on ports [10] and for investigating the dynamic behaviour of the transfer process at the ports too [11]. Also, the simulation model performs procedures which increase the traffic safety [12].

In general, the models for dimensioning of railway facilities can be: analytical, graphical, models which use theory of probability and mathematical statistics and models of applied Queuing Theory based on mathematical modelling of technological processes and computer simulation [7]. Also, the simulation models can show how technological processes in a station could be optimally controlled via mathematical methods and computer hardware [13].

Analytical models for determining the capacities do not take into account technological processes and do not provide multivariate solutions. Accuracy of these models is much smaller in relation to others. Graphical models directly depend exclusively on the train schedules and standardized technological time durations of activities and operations. These models are tested within each change of train schedule. The application of the Queuing Theory gives good results in the analysis and determination of stochastic systems. The main problem in applying this theory is the choice of best suited queuing system to solve the set of problems. A specific problem is determining the exact distribution of the input stream and the time of its serving.

The trains traffic process, starting from the moment of the entry of trains at the beginning of the observation, the formation of the driving routes, the station entrance for trains, layover for technological operations, exiting the station and so on, is best described by simulation models.

A simulation is the imitation of an operation of a real-world process or system over time. It is the representation of dynamic behaviour of a system by moving it from state to state in accordance with well-defined rules. Simulation methods provide a model, which is as close as possible to reality, to validate a given timetable [1].

Often, the results of the simulation models are compared with results of other models.

In the literature there are no papers which deal with optimization of the work in border stations using simulation modelling, but there are presented simulation models which concern the movement of trains to advance adopted technology in the transit railway stations.

Border stations are points in which the train's layover time is significant, especially in the freight traffic. The trains in the border station are held for passenger exchange, police and customs formalities, locomotives change, adding or removing wagons, technical and commercial inspection, receiving documentation from and off the trains, making documentation and so on. Often, the border station represents point of turnover for the passenger trains in internal traffic. All those standings directly affect the capacities of the border station and it is all on the grounds of the existing technology in processing of trains.

For example, among EU members the trains are kept in border station in order to perform the customs procedure, and between certain countries there is some retention of trains for carrying out railway technology operations.

This paper presents a simulation model for technology and infrastructure facilities optimization in the border railway stations based on the technological processes in border stations and in other train stations. Results are compared with results obtained by analytical model.

The model is tested on the example of the Kremenica border railway station in Macedonia, which is planned in the annual plan (2011-2013) of the Macedonian government for reconstruction, and it is a border station between a country that borders on the EU (Macedonia) and EU Member State (Greece).

2. TYPE AND PURPOSE OF KREMENICA STATION

The Kremenica station is located on the main railway line Veles-Bitola-Kremenica-Greece border, which is a part of the Corridor X branch "D". Kremenica also is a border station between the Macedonian Railways (MZ) and the Greek Railways (OSE) (*Figure 1*). Kremenica is a mixed station for receipt, processing and dispatching passenger and freight trains in internal and international traffic. The station has two tracks for receipt and dispatch of trains, which stop to exchange passengers, locomotive change and customs procedures, while the loading and unloading of freight wagons is envisaged to be made on the reversing triangle (*Figure 5*). The neighbouring stations are Bitola station (MZ) and Mesonision station (OSE).

3. ANALYTICAL MODEL

Capacities which are determined with the analytical model are carried out in equations (1), (2), (3) and (4).

$$T_{ot} = N \cdot (t_{rt} + t_{st} + t_{dt}) \tag{1}$$

$$t_{rt} = t_{st} + 0.06 \cdot \frac{L_{rr}}{V_{ent}} + t_{sr} \tag{2}$$

$$t_{dt} = t_{st} + 0.06 \cdot \frac{L_{dr}}{V_{ext}} + t_{sr} \tag{3}$$

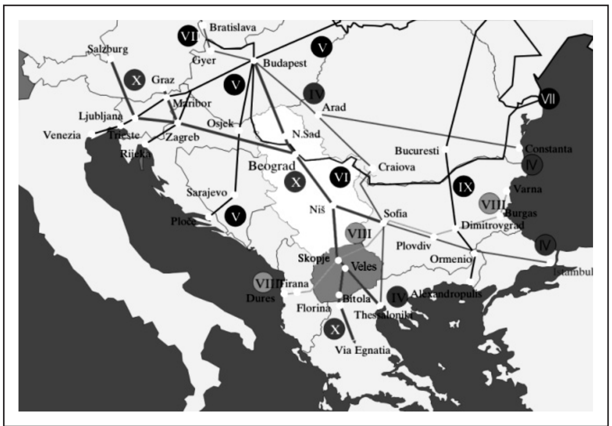

Figure 1 - Pan-European Corridors

$$n_{track} = \frac{T_{ot}}{\left(T_w - \sum t_{hs}\right) \cdot \alpha_{usage}} \tag{4}$$

The meaning of the parameters used:

- T_{ot} – Total occupation time of the tracks by the trains (min)
- L_{rr} – Reception route length (m)
- N – Number of trains
- V_{ent} – Train speed at station entry (km/h)
- t_{rt} – Time needed to receive the train (min)
- t_{agree} – Time needed for agreement between the stations (min)
- t_{st} – Train standing time (min)
- L_{dr} – Dispatching route length (m)
- t_{dt} – Time needed to dispatch the train (min)
- V_{ext} – Train speed at station exit (km/h)
- t_{sr} – Time needed to set the route (min)
- α_{usage} – Track occupation coefficient
- T_w – Station working hours (min)
- n_{track} – Required number of tracks
- $\sum t_{hs}$ – Time at the end of the day for holding the tracks, shift, and such.

In this paper four alternatives for freight traffic and five alternatives for passenger traffic are analyzed (*Table 1*).

On the basis of the results obtained for freight transport for both technologies (classical and combined) transport, the number of tracks is in the range between 1 and 7 (*Figure 2*), while in the passenger transport from 1 to 3 tracks depend on the alternative (*Figure 3*).

And on the basis of the results obtained by the analytical model it can be concluded that the existing capacity of the station Kremenica can satisfy the needs only for the traffic management of trains in case when they enter the station within the interval between 4 and 3 hours provided one track is only for passenger traffic and other tracks are for freight traffic (classical and combined transport).

Table 1 - Variations with interval of incoming

Type of transport	Alternatives	Interval (h)	Number of pairs of trains per day	Number of trains per day
Freight	1	1 train in 4h	6	12
	2	1 train in 3h	8	16
	3	1 train in 2h	12	24
	4	1 train in 1h	24	48
Passenger	1	1 train in 6h	4	8
	2	1 train in 4h	6	12
	3	1 train in 3h	8	16
	4	1 train in 2h	12	24
	5	1 train in 1h	24	48

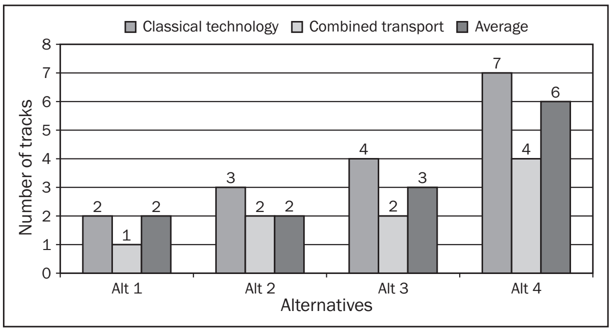

Figure 2 - Number of tracks for all kinds of railway freight transport

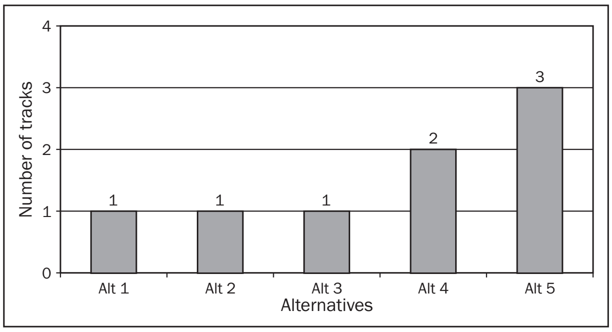

Figure 3 - Number of tracks for railway passenger transport

4. SIMULATION MODEL

For the Kremenica station capacity and technology modelling GPSS (General Purpose Simulation System) Simulation programme is used. The simulation models of the traffic processes using the GPSS are presented in papers [14], [5] and [7]. According to the model needs, the entry and departure speeds are defined.

The train retention time (t_{rt}) in the model devices is calculated in the following equation:

$$t_{rt} = \frac{3.6 \cdot (L + \ell_{train})}{V} \quad \text{(s)} \tag{5}$$

where:

- L – length of the elements in the real system (m);
- ℓ_{train} – length of train (m);
- V – train speed when the train is passing the observed device (km/h).

For the purposes of the model the length of the elements (devices) of the real system are calculated, and the retention time on them. However, the real time, when the device is busy and the train is passing, is much longer. The train retention at the first element in the process of formation of the driving route[2] is calculated according to equation (6). In the modelling, according to the Kremenica station dependence table for this model (*Table 2*), it is taken that one driving route includes several devices (example: one or more group switches, tracks etc.).

$$T_{rte} = t_{rft} + t_{spt} + \frac{3.6 \cdot (L + \ell_{train})}{V_{ent}} \quad \text{(s)} \tag{6}$$

where:

- t_{rft} – driving route formatting time (s);
- t_{spt} – signal perception time when the trains are moving at classical speed (s);
- V_{ent} – average train speed when the train is entering the station (km/h).

Track occupation time of the "*n*" element in the driving route (T_{rte_n}) is calculated by the following equation:

$$T_{rte_n} = t_{rft} + t_{spt} + \sum_{i=1}^{n-1} t_{rt_i} + t_{rt_n} \quad \text{(s)} \tag{7}$$

where:

- $\sum_{i=1}^{n-1} t_{rt_i}$ – train retention time sum on the previous devices on the driving route (s);
- t_{rt_n} – train retention time on the "*n*" device (s).

Similar logic applies when it comes to the departure driving. The occupation time of the "*i*" track device in the shunt-dispatching yard is calculated by the equation:

$$T_{rte_i} = t_{rft_i} + t_{spt} + t_{dt} + \frac{3.6 \cdot \ell_{train}}{V_{ext}} \quad \text{(s)} \tag{8}$$

where:

- V_{ext} – average speed when the train leaves the station (km/h);
- t_{dt} – train dispatch time (s).

Track occupation time of the "*n*" output device in the shunt-dispatching yard is:

$$T_{rte_n} = t_{rft} + t_{dt} + \sum_{i=1}^{n-1} t_{rt_i} + t_{rt_n} \quad \text{(s)} \tag{9}$$

The boundaries for the purposes of the model are defined. The trains in the model are observed from the dispatch signal of the Bitola station. OTSEK1 device is an input device in the model of the Kremenica station on the side of the Bitola station. The train departure out of the system is performed when the train leaves the last device, or the section following the Kremenica station dispatch signal on both sides.

The movement of the trains in the model as in the real system, the same as in the model, is subject to certain regulations. For the train movements through the station many different types of routes are used: entry, dispatch and transit routes and overlap routes.

Due to the consideration of all the necessary and possible driving routes for this model we developed route table (according to the train movement dependence table for this model), in which the realization of all simultaneous driving is enabled. A dependence table is made also (*Table 2*); this table represents the track occupation dependence, signal dependence and model devices dependence on different routes. According to this table in the model

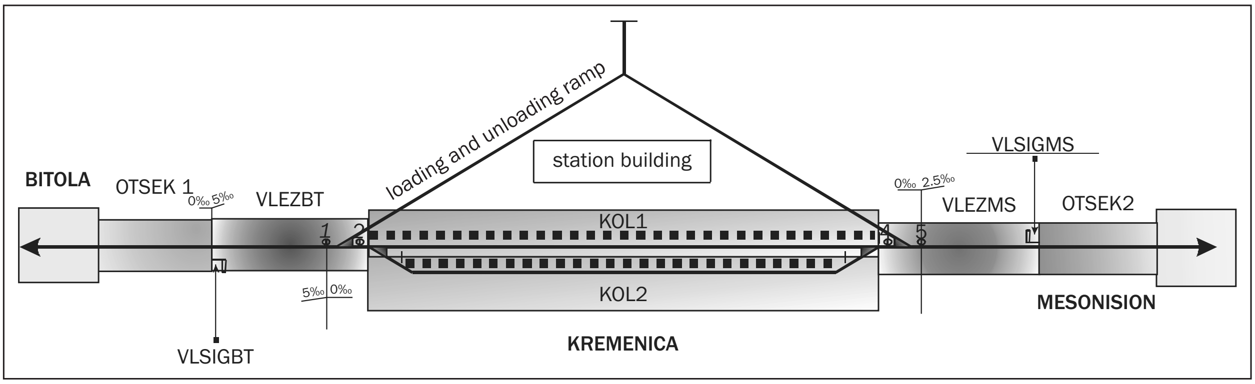

Figure 4 - Scheme of the devices used in the model simulation

Table 2 - Kremenica station dependence table

Drive route	track	symbol	Drive route dependence								Switches dependence				Signal dependence		Model devices dependence					
			B1	B2	1B	2B	M1	M2	1M	2M	1	2	3	4	VLSIGBT	VLSIGMS	Otsek1	VLEZBT	KOL1	KOL2	VLEZMS	Otsek2
Entry from Bitola side	1	B1		×	×	×	×	×	×	×	+	+			ALLOW	DENIED	↑	↑	↑		↑	
	2	B2	×		×	×	×	×	×	×	+	-			ALLOW	DENIED	↑	↑		↑	↑	
Exit to Bitola side	1	1B	×	×		×	×	×	×	×	+	+					↑	↑	↑			
	2	2B	×	×	×		×	×	×	×	+	-					↑	↑		↑		
Entry from Mesonision	1	M1	×	×	×	×		×	×	×			+	+	DENIED	ALLOW		↑	↑		↑	↑
	2	M2	×	×	×	×	×		×	×			-	+	DENIED	ALLOW		↑		↑	↑	↑
Exit to Mesonision	1	1M	×	×	×	×	×	×		×			+	+					↑		↑	↑
	2	2M	×	×	×	×	×	×	×				-	+						↑	↑	↑

the following rules for safe routes regulation are used:

1. When a route is formed (entry route means that overlap route is included as well), another route can be formed if and only if these two do not overlap, intersect or touch;
2. All relevant signals whose implementation could jeopardize the route (front, ends, or jeopardizing by overcoming), should show a signal of prohibited driving;
3. The route in any of its parts must be unoccupied by other vehicles or bands.

The model uses the following devices:

1: OTSEK1	Space between the dispatch main signal of Bitola station and the entry main signal of Kremenica station.
2: VLEZBT	Space between the entry main signal in Kremenica station (Bitola side) and the first switch in Kremenica station
3: KOL1	1st track
4: KOL2	2nd track
5: VLEZMS	Space between the entry main signal in Kremenica station (Mesonision side) and the first switch in Kremenica station
6: OTSEK2	Space between the exit main signal of Mesonision station and the entry main signal of Kremenica station.

The logical switches in the model are in the function to allow the directions of driving:

1: VLSIGBT	Kremenica station main entry signal from Bitola station side
2: VLSIGMS	Kremenica station main entry signal from Mesonision station side

In the model the following system warehouses are used:

1: STANBT	Bitola station
2: STANMS	Mesonision station

In the model two waiting lines are used, as follows:

1: REDBT	Waiting line for Kremenica station from Bitola station side
2: REDMS	Waiting line for Kremenica station from Mesonision station side

In the model three types of trains are processed, such as: passenger, freight transport (classical technology) and freight transport (combined transport technology). Based on the statistical examination it is established that 25% of the trains are passenger trains, and 75% are freight trains, out of which 50% are classic freight and 50% are intermodal.

The model tests are made for the following terms of train traffic with the alternatives included:

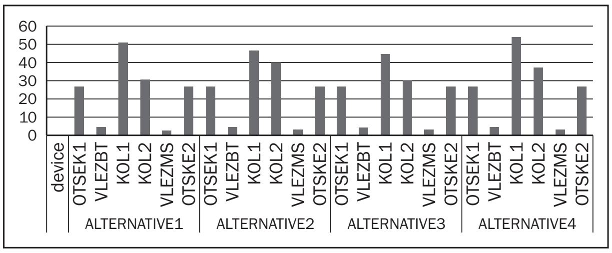

Figure 5 - Average train standing time per device (min)

- ALTERNATIVE1 (for 1 pair of trains in 240 minutes),
- ALTERNATIVE2 (for 1 pair of trains in 180 minutes),
- ALTERNATIVE3 (for 1 pair of trains in 120 minutes),
- ALTERNATIVE4 (for 1 pair of trains in 60 minutes).

The generation of trains is performed by uniform distribution in minutes, such as: *ALT1[210,270]*, *ALT2[160,200]*, *ALT3[105,135]* and *ALT4[50,70]*.

The train layovers in order to perform technological operations are carried out according to normal distribution. The parameters of the normal distribution, in minutes, for passenger trains are $N_p(30,10^2)$, for the classical $N_c(120,30^2)$ and for the combined $N_i(60,20^2)$.

The testing results are shown in Figures: 5, 6, 7, and Tables: 2, 3 and 4.

According to the test results of the model it can be seen that the use of track facilities in the neighbouring stations Bitola and Mesonision ranges up to 13%. That indicates that their facilities meet the needs of all variants (*Table 3*). However, at variant 4, because of the impossibility of the Kremenica station capacity and the station facilities to receive trains, there is a significant train retention at the Mesonision and Bitola stations. At the Bitola station an average of 1.487 trains are waiting for releasing the capacities of Kremenica by standing up to 93 minutes and 2.6 trains from Mesonision side enter with max standing time of 164 minutes. In one period of time of the simulation in the fourth variant even eight trains waited in Mesonision for the release of the capacities of Kremenica.

The capacities of the Kremenica station, according to the results of the simulation model testing, can serve traffic if variants 1 and 2 took place for the planned working technology (Figures 5 and 6, *Table 4*). The retention time of the trains on the devices, according to this variant is in accordance with the intended operation of technology and regulation of traffic.

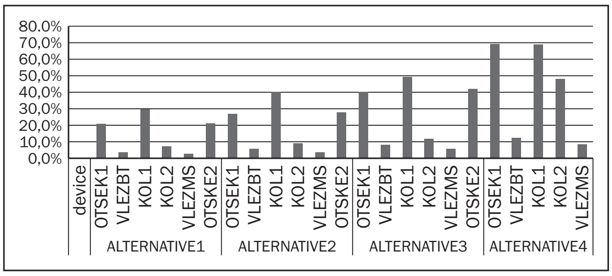

Figure 6 - Device percentage occupancy

The capacity utilization for variant 3, according to the results of testing ranges in the tolerant limits of utilizing track capacities (*Figure 5* and 6, *Table 4*). In this case the traffic flow occurs stopping trains at station entry signals in 2 cases with an average retention for about 5 minutes, which also may be insignificant (*Table 5*).

However, in version 4 it can be seen that the devices OTSEK1, OTSEK2 and KOL1 are occupied over 70% of the time (Figures 5 and 6, *Table 4*), which means that these facilities cannot serve the anticipated vol-

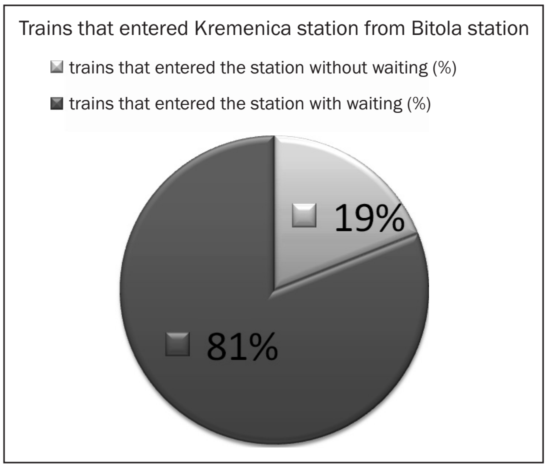

Figure 7 - Trains retention at entry signal (Variant4)

Table 3 - Trains standings at the system warehouses

	System warehouse	Average number of trains	Use of the systems warehouses (%)	Average train standing time in system warehouses (min)	Max. number of trains in system warehouses
ALTERNATIVE 1	STANBT	0.349	1.7%	81.9	2
	STANMS	0	0	0.0	1
ALTERNATIVE 2	STANBT	0.51	2.60%	90.2	2
	STANMS	0	0	0.0	1
ALTERNATIVE 3	STANBT	1.268	6.3%	163.4	4
	STANMS	0	0	0.0	1
ALTERNATIVE 4	STANBT	1.487	7.40%	93.1	3
	STANMS	2.601	13.00%	163.8	8

Table 4 - Train standing time per devices

	Devices	Rate of exploitation	Number of inputs	Average retention time (min)
ALTERNATIVE1	OTSEK1	20.60%	11	27.0
	VLEZBT	3.50%	11	5.0
	KOL1	29.40%	7	50.7
	KOL2	7.40%	3	30.8
	VLEZMS	2.60%	10	3.3
	OTSEK2	21.00%	10	27.0
ALTERNATIVE2	OTSEK1	26.70%	15	27.0
	VLEZBT	5.40%	14	5.0
	KOL1	39.70%	11	46.7
	KOL2	9.00%	3	40.0
	VLEZMS	3.60%	14	3.4
	OTSEK2	27.60%	14	27.0
ALTERNATIVE3	OTSEK1	39.90%	22	27.0
	VLEZBT	8.00%	21	5.0
	KOL1	51.60%	17	44.8
	KOL2	11.80%	5	30.4
	VLEZMS	5.60%	22	3.6
	OTSEK2	41.80%	22	27.0
ALTERNATIVE4	OTSEK1	69.40%	37	27.0
	VLEZBT	12.60%	37	5.0
	KOL1	68.90%	18	53.9
	KOL2	48.00%	18	37.4
	VLEZMS	8.80%	36	3.4
	OTSEK2	67.50%	36	27.0

ume of traffic (1 pair of trains per 60 minutes, or 2 trains per 60 minutes). It should also be noted that in this variant there is very high retention of trains at entry signals (*Table 5*). As many as 81% of trains from Bitola and 100% from Mesonision are stopped at the entry signal (*Figure 7*).

If the trains were arriving as in variants 1 and 2, according to the simulation model the existing station capacity would be sufficient. The same was confirmed during testing of the capacity with the analytical model. It shows that the projected station working technology corresponds to its capacity.

In variants 3 and 4 an increase of the capacities is needed or improvement of technology of train processing. This particularly applies to the freight trains in which greater retention occurs at entry into the system for processing or waiting in queue. Also, the analytical model proved to consider the capacity expansion if the trains come under option 3 and 4. This means that if the trains come within the 120min interval, the existing facilities have limited ability to serve traffic. But the incoming interval of less than 120min required new station facilities. In favour of this are the results obtained from the testing that showed a huge waiting time at the beginning of the train processing, which indicates the need for expanding the capacity and intervention on the technology of work.

5. TECHNICAL AND ORGANIZATIONAL MEASURES TO REDUCE THE RETENTION OF TRAINS AT THE BORDER STATION KREMENICA

All operations and activities carried out at border stations are necessary, and the quality analysis can be divided on those pursued by public authorities and those run by the railways.

In the near future the Kremenica railway station must be converted into common rail station for two administrations (MZ and OSE). The prerequisite is the basic assumption under which the total retention time of passenger and goods trains could be reduced on both sides and could thus reduce the total travel time. This would enhance the competitiveness of railway transport.

If Kremenica station was a joint border station, it would accommodate all competent railway authorities for the treatment and control of trains (MZ and OSE staff) and state departments of customs police authorities from Macedonia and Greece, and the presence of the competent inspection services (sanitary, environmental, veterinary, etc.).

Besides, modern trends in railway traffic try to use the international rail network for data transmission – ORFEUS (Open Railway Freight EDI System) and the electronic waybill form – CIM, which could significantly reduce the standings of trains at border stations.

Table 5 - Trains retention (in queues)

	Lines	Max	Used capacity (trains)	Number of entries	Average standing time (min)	Present state
ALTERNATIVE 3	REDBT	1	0.11	2	5.025	0
	REDMS	0	0	0	0	0
ALTERNATIVE 4	REDBT	2	0.569	22	38.98	1
	REDMS	8	2.601	18	211.98	8

6. CONCLUSION

Running the train traffic is just one of the many complex processes that take place in the complex system of railways. Railway processes are suitable for modelling and simulation; therefore, analytical models do not always give optimal solutions, and the experiments in the real system could be lengthy, costly and risky. So, the model developed in this paper allows dimensioning of technology and capacity based on the application of analytical models and simulation of train traffic through the border station Kremenica.

On the basis of the results obtained from the testing of the models it can be concluded that the station would satisfy the needs for processing trains in intervals larger than 120 minutes.

The measures offered are based on the experience of railways which belong to the EU, and members of the UIC (International Railway Union) and thus the measures have to be applied by MZ and OSE. So, turning the station into a common border station (common to both countries) as well as by implementing new information technologies in the process of handling and dispatching trains, would increase the processing speed of the trains. It is also essential in the joint station Kremenica for all operations of the railways and the authorities to be maximally simplified and organized as parallel work of individual operations as much as possible.

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АПСТРАКТ

МОДЕЛ ЗА ДИМЕНЗИОНИРАЊЕ НА ТЕХНОЛОГИЈАТА И КАПАЦИТЕТИТЕ ВО ГРАНИЧНИ ЖЕЛЕЗНИЧКИ СТАНИЦИ

Вклучувањето на националните железнички мрежи во Европските коридори условува одредени нивни редефинирања и модификации. Посебни места на железничките мрежи претставуваат железничките станици, кои посебно во југоисточна Европа, треба да се модернизираат. Едно од главните прашања при изградбата или реконструкцијата на железничките станици претставува димензионирањето (проектирањето) на инфраструктурните капацитети во нив. Димензионирањето на инфраструктурните капаците е во директна зависност со предвидената технологија на работа и планираниот обем на сообраќај.

Во овој труд е претставен симулационен модел кој овозможува димензионирање на капацитетите во граничните железнички станици врз база на дефинирана технологија на работа и обем на сообраќај.

КЛУЧНИ ЗБОРОВИ

моделирање, симулација, капацитети, технологија, гранични железнички станици

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