sciendo

Transport and Telecommunication, 2024, volume 25, no. 1, 11–19
Transport and Telecommunication Institute, Lomonosova 1, Riga, LV-1019, Latvia
DOI 10.2478/ttj-2024-0002

TRANS-CASPIAN INTERNATIONAL TRANSPORT ROUTE INFRASTRUCTURE ASSESSMENT USING SIMULATION MODELLING

***Azat Zhumanov*[1], *Zhandos Kegenbekov*[2], *Jurijs Tolujevs*[3]**

[1]*Al-Farabi Kazakh National University*
Al-Farabi Avenue 71, 050040, Almaty, Kazakhstan
[2]*Kazakh-German University*
Pushkin 111, 050010, Almaty, Kazakhstan
[3]*Transport and Telecommunication Institute*
Lomonosova 1, Riga, LV-1019, Latvia
[1]*azat_jumanov@mail.ru*
[2]*kegenbekov@dku.kz*
[3]*tolujevs.j@tsi.lv*

The Trans-Caspian International Transport Route (TITR) is one of the main transport corridors between China and Europe. It passes through the territory of Kazakhstan, as well as the countries of the South Caucasus, Turkey, and Iran, and contributes to the full realisation of transit and export opportunities of these countries. Each country participating in the development of TITR is implementing projects to increase the capacity of its transit infrastructure, but the potential of this route has not yet been fully realised. The reason for this is both high tariffs for sea and rail transport and insufficiently short transport times, which are dependent on the parameters and methods of using the infrastructure. This paper is devoted to the study of the TITR railway infrastructure located in Kazakhstan. The developed simulation model allows estimating the impact of infrastructure parameters of the railway track on the movement time of a container train from the PRC border to the ports of Aktau and Kuryk on the Caspian Sea coast.

Keywords: Trans-Caspian international transport route, rail transportation, agent-based simulation, AnyLogic

1. Introduction

The Trans-Caspian International Transport Route (TITR) is an international transport corridor that runs through China, Kazakhstan, the Caspian Sea, Azerbaijan, Georgia and further to Turkey and European countries. "The Trans-Caspian International Transport Route" is an organisation that unites and represents the interests of a few countries and companies located in the regions through which the historic Great Silk Road passed. It helps to simplify administrative procedures, create a competitive environment and maximise efficiency for companies from different countries, including those not geographically located directly on the TITR. The most important component of the TITR is railway transport within the territory of the Republic of Kazakhstan between the border with PRC and ports on the Caspian Sea coast. For east-west shipments, this route starts at Dostyk and Khorgos (Altynkol) border stations, passes through Arys and Shalkar stations and ends at Aktau-Port and Kuryk-Port stations. The TITR is the first (yellow) route of those shown in the map legend in Figure 1, where it is presented as one of the trans-Asian railway routes (CAREC, 2021).

TITR is one of the routes being developed under the Central Asia Regional Economic Cooperation Programme (CAREC). In 2017, the eleven member countries of the CAREC Programme adopted a Railway Strategy (CAREC, 2017) to expand the role of rail transport in the region. The Strategy aims to accelerate the identification, preparation and financing of feasible railway investment projects and, at the same time, to promote the commercialisation and reform of railways to improve their efficiency.

As shown in Figure 1, Kazakhstan provides the shortest routes for many categories of trans-Asian rail transport. The country is already a leading provider of such freight transport and this role is expected to increase in the future. In 1997, Kazakhstan Temir Zholy (KTZ), a state-owned enterprise, was established to manage and operate the country's railway network. Between 2001 and 2016, KTZ implemented a major investment programme to build new railway lines. Many of these were aimed at reducing distances for east-west transport. Despite the large amount of work completed, a negative factor remains the high number of single-track lines, which at the beginning of 2021 accounted for almost 70% of all railway tracks in Kazakhstan. Demand for utilisation of TITR resources is constantly increasing. In addition to freight traffic from China to Europe, each TITR member country has its own interests in exporting and selling its products on the world market. On single-track lines, there are already sometimes problems today due to their insufficient capacity, and in the future they may become real bottlenecks. The report (CAREC, 2021) states that this situation can be prevented if KTZ identifies future bottlenecks in advance and increases the capacity of the relevant infrastructure elements.

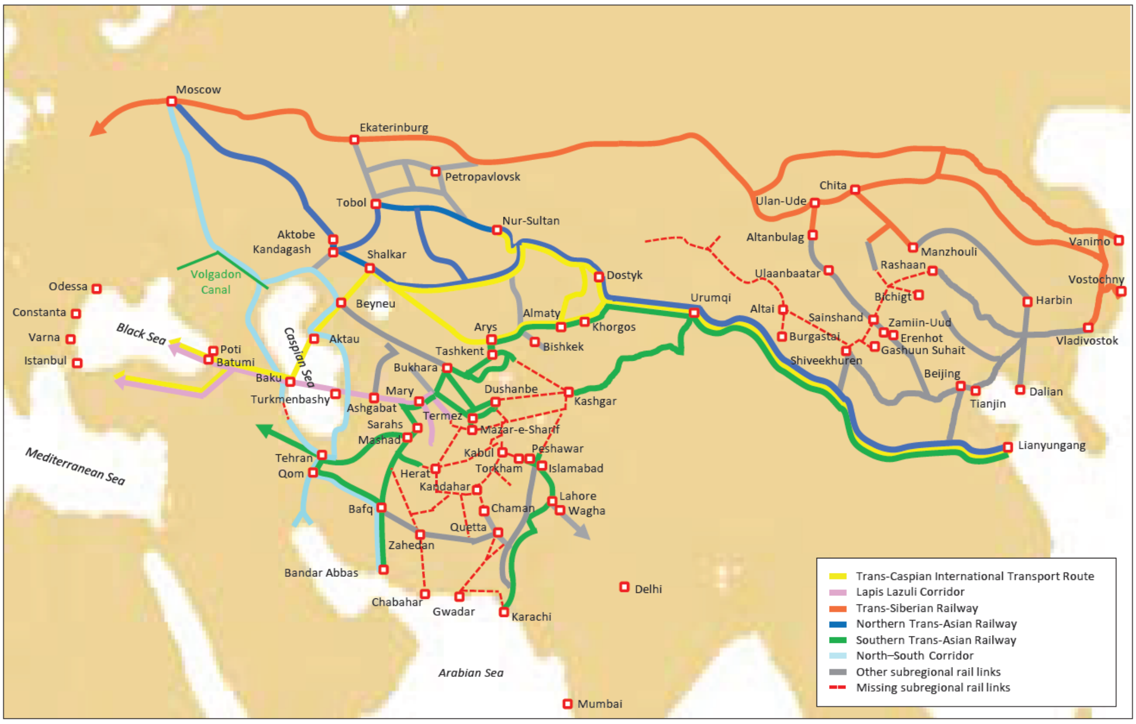

Figure 1. Trans-Asian railway routes scheme (CAREC, 2021)

The main objective of this paper is to develop a tool that can be used to quantitatively analyse the impact of infrastructure characteristics on the journey time of container block trains. This analysis applies primarily to single-track sections of railway track whose capacity depends on the number of sidings. The tool has been developed in the form of a simulation model based on the agent-based paradigm, and this model has been applied to the TITR process study.

In the overview part of this paper, three approaches to modelling TITR-type transport corridors are discussed. The first approach is illustrated by two economic macro models that have already been applied to study economic processes in TITR. An example of the application of the second approach is the forecast model associated with the Akhangaran-Tukimachi-Syrdarya railway line. The third approach is the basis for simulation modelling of train movement processes in any given railway network.

2. Approaches to modelling a transport corridor based on the use of the railway network

The first approach is based on the use of a universal economic macromodel, which can be considered static, since the time factor is not explicitly taken into account in it. The essence of the second approach is the application of classical forecasting models, in which the forecasted indicator is calculated for several moments of discrete time. Finally, the third approach involves the construction of a dynamic simulation model in which events in the railway network can be displayed both at the microscopic and macroscopic level at any moments of continuous time.

2.1. Analytical models

The paper (Kumagai *et al.*, 2021) describes the application of a numerical simulation model that the Institute of Developing Economies (IDE) in Japan has been developing since 2007. The model is called

Institute of Developing Economies-Geographical Simulation Model (IDE-GSM). The theoretical basis of the model is the model of monopolistic competition, which is associated with the name of Krugman (Krugman, 1991). IDE-GSM is characterised as a general equilibrium simulation model based on spatial economics. One of the objectives of the model's development is to assess the impact of trade and transport measures on the regional economy at the sub-national level. The model belongs to the global class, as the IDE-GSM dataset already covered more than 3000 regions in 98 countries as of early 2019. The model's form of existence is a set of formulas for high-dimensional matrix calculations. Using IDE-GSM, the authors estimate the impact of CAREC and TITR corridors on industries in the regions that surround these corridors. The authors show a chart in which the regions of Kazakhstan show large benefits from the establishment of TITR. GRDP (gross regional domestic product) should increase by an average of US$20-30 per capita per year.

The authors of the paper (Watanabe *et al.*, 2021) in 2017 developed the GLINS (global logistics intermodal network simulation) model for modelling freight flows in a global intermodal transport network and now apply it to the Eurasian continent. Particular attention is paid to modelling the impact of TITR on the economy of Kazakhstan. The inputs to the model are freight transport demand, as well as delivery cost, frequency, speed and distance of transport. The paper describes scenarios that include, inter alia, the following infrastructure development measures:

- construction of new railways through Kazakhstan in the east-west direction, as well as railways connecting Kazakhstan and Iran via Turkmenistan along the Caspian Sea;
- doubling the average train speed in Kazakhstan;
- increasing the frequency of the Caspian ferry between Aktau (or Kuryk) and Baku from one per week to three per day.

As modelling results, the authors show the annual number of containers transported by land from the PRC to the countries of the South Caucasus, Turkey and Iran. These volumes are calculated for different scenarios, which include not only infrastructure development measures, but also reductions in ferry and railway costs, as well as reductions in border barriers between the countries.

The paper (Kotenko *et al.*, 2021) proposes a mathematical model that is based on the assumption that a curve (straight line or parabola) adequately describes the dynamics of freight traffic change over 20 years. The authors apply the usual approximation method to determine two coefficients of the first degree polynomial and three coefficients of the second degree polynomial for freight traffic forecasting models on a particular railway line. Based on traffic data for the previous 10 years, the model calculates the traffic volume for the next 10 years. The second step in applying the model is to convert the expected traffic volume into the required capacity of the railway line. Specialists need to know the dependencies of throughput capacity on infrastructure elements and, based on this knowledge, plan measures for their further development.

The authors illustrate the application of the model on the example of the Akhangaran-Tukimachi-Syrdarya railway line, which affects the operation of the entire railway of the Republic of Uzbekistan and is an important component of transport corridors for regular freight traffic from China to Central Asia and Europe.

2.2. Dynamic simulation models

Dynamic simulation models of the railway network are created using both general-purpose simulation modelling packages and specialised packages. It has been a tradition for many years to divide such models into microscopic and macroscopic models (Johansson *et al.*, 2022).

Very often in microscopic models the station area with all related infrastructure is represented with high accuracy. The graphical background of the model is a plan of the station area with all track sections, switches, dead ends, etc. The position of each train can be determined to the nearest metre. The model should reflect the real train and shunting locomotive traffic control strategies used by dispatchers on the railway. In other models of this class, station areas are shown in less detail, but entire track sections and blocks are considered, for which train schedules can be investigated or even optimised. In European countries, RailSys (Radtke and Hauptmann, 2004) and OpenTrack (Nash and Huerlimann, 2004) are the most used packages for microscopic modelling of processes in the railway network, but the total number of such packages is very large.

An example of the application of the OpenTrack package for microscopic modelling of an 18.35 km track section in the Czech Republic is described in (Tischer *et al.*, 2020) and for another 17.12 km track section in (Široký *et al.*, 2021). Both models included three stations each and several intermediate stop points. The authors (Michal *et al.*, 2017) developed the RailNet microscopic modelling package and applied it to investigate the capacity of the track network at the Port Kembla Coal Terminal in New South Wales, Australia.

Macroscopic models are used to study relatively large parts of the railway network. They represent only track sections, stations and sidings as infrastructure elements, and only train departures and arrivals as events. In such models it is sometimes possible to observe the movement of hundreds of trains simultaneously. The best known is the PRISM model (Zinser *et al.*, 2019), which includes the possibility of using also microscopic modelling elements. This model allowed simulating a single day of operation of the German railway network with approximately 40,000 trains in less than a minute. In (Moeinaddini *et al.*, 2017), an example of macroscopic modelling of a railway network within Iran, which includes 224 stations and 13,000 km of railway tracks, is presented. The model is created using the Visual Basic programming language. The principles of using different levels of process representation detail in railway network models are most clearly outlined in (Cui *et al.*, 2018) and (Cui and Martin, 2011).

The widely used AnyLogic simulation modelling package includes Rail Library, which focuses on microscopic modelling (Divis and Kavicka, 2014). The authors discuss the results of Rail Library testing on an example of a track section that includes three stations. In (Amorim *et al.*, 2020), the application of the Process Modeling Library of the AnyLogic package for microscopic simulation of complex handling processes of 16 types of freight wagons on 27 parallel tracks at the Port of Paranaguá, Brazil is reported.

One of the authors of this paper has experience in creating a large simulation model that shows possible passenger flow dynamics on the Rail Baltica high-speed railway (Tolujew *et al.*, 2018). When completed, this railway will connect five major cities from Berlin to Tallinn. The model is based on System Dynamics principles, and it is built using the ExtendSim package. The model investigates the transport of approximately 1,2 million passengers over the course of a year, considering the dynamics associated with the seasons.

To solve the problem posed in this study, we decided to build a macroscopic model using the agent-based paradigm, which is implemented using the AnyLogic package.

3. Description of the conceptual model

The object of modelling is the process of container trains movement along the route connecting the border stations Dostyk and Altynkol with the stations on the Caspian Sea coast Aktau-Port and Kuryk-Port (Figure 2). The input data of the model are the parameters of the track sections between all stations shown in Figure 2, as well as the standard delay times of trains at these stations. A separate analytical model is used to determine the required number of sidings on single-track sections, at which the waiting time for a block to be cleared before the next siding can be minimized. The model does not consider the actual number of sidings, as the purpose of the modelling is not to represent train movements "as is", but to estimate the future throughput limits of the route.

Figure 2. Container train route investigated

The main primary indicator of model operation is the route journey time, excluding train handling time at origin and destination stations, as these processes are independent of track throughput and are the subject of other studies. The route journey time includes the journey time for each section between the stations shown in Figure 2, including delays at sidings, as well as the planned delay time at the station related to train processing. The model is stochastic, as all delay times can be represented as random variables using appropriate distribution laws.

3.1. Modelled route parameters

The section parameters shown in Table 1 are constant model inputs that do not change during the simulation experiments. The data shown in Table 1 are used when moving along the route in both directions. Most of the sections are single-track, so it is often necessary to create sidings. As noted above, the number of sidings for each section is determined using a separate model. The parameter "number of trains pairs" characterises the loading of the section by both passenger and goods trains, which affects the movement of the modelled container trains. The parameter "delay at end point" is the nominal time of train processing operations at the intermediate station. This time is used in the model as a mathematical expectation in constructing the corresponding exponential distribution with a shift. In the column "reason for the delay" the train handling operations are briefly described. The case of "only staff" means that only locomotive crew change takes place, while in the case of "locomotive & staff" a locomotive change is added.

Table 1. Parameters of sections between stations of the route

Section no.	Starting point	End point	Distance (km)	Number of tracks	Number of trains pairs	Delay at end point (min)	Reason for the delay
1	Altynkol	Shelek	177.2	1	1	20	only staff
2	Shelek	Zhetigen	106.0	1	1	10	only staff
3	Zhetigen	Almaty-1	43.2	1	7	40	locomotive & staff
4	Almaty-1	Otar	155.4	1	9	20	only staff
5	Otar	Shu	155.8	1	9	20	only staff
6	Shu	Taraz	232.8	2	15	40	locomotive & staff
7	Taraz	Arys-2	295.9	2	15	40	locomotive & staff
8	Arys-2	Turkestan	108.9	1	11	20	only staff
9	Turkestan	Shieli	156.4	1	11	20	only staff
10	Shieli	Kyzylorda	127.9	1	11	40	locomotive & staff
11	Kyzylorda	Zhosaly	147.0	1	9	20	only staff
12	Zhosaly	Kazaly	173.4	1	9	20	only staff
13	Kazaly	Saksaulsky	179.9	2	9	20	only staff
14	Saksaulsky	Shalkar	165.8	2	9	40	locomotive & staff
15	Shalkar	Tassay	135.0	1	1	20	only staff
16	Tassay	Beyneu	332.5	1	1	20	only staff
17	Beyneu	Mangystau	403.2	1	5	40	locomotive & staff
18	Mangystau	Aktau-Port	10.0	1	5	-	-
19	Aktau-Port	Kuryk-Port	86.0	1	1	-	-
20	Dostyk	Aktogay	303.7	1	1	40	locomotive & staff
21	Aktogay	Ushtobe	255.7	1	7	20	only staff
22	Ushtobe	Saryozek	109.7	1	7	20	only staff
23	Saryozek	Zhetigen	148.0	1	7	10	only staff

3.2. Estimation of the required number of sidings between stations with planned stops

This model is used to determine the minimum number of sidings for a section between two stations with a planned stop. This number of sidings will allow a given number of pairs of trains to pass within a day or some other specified time interval without waiting for a block to be cleared before the next siding. The model is idealized, since it assumes that trains in both directions will depart at the same time intervals τ_{int}, and to travel a section of length l_{path} without stopping at an average speed v_{path} each train will need the following time:

$$\tau_{path} = \frac{l_{path}}{v_{path}}. \tag{1}$$

The minimum number of sidings depends on only one parameter k, which is defined as the fraction of time τ_{int} with respect to time τ_{path}:

$$k = \frac{\tau_{int}}{\tau_{path}}. \quad (2)$$

The empirical formula for calculating the theoretical number of sidings is as follows:

$$n_{theor} = \frac{2}{k}. \quad (3)$$

The real number of sidings n_{real} is determined using the following algorithm for interpreting the numerical value of n_{theor} and k:

if n_{theor} is an odd integer, then $n_{real} = n_{theor}$;
if n_{theor} is an even integer, then $n_{real} = n_{theor} - 1$;
if n_{theor} is a fractional number and its integer part $int(n_{theor})$ is an odd number, then $n_{real} = int(n_{theor})$;
if n_{theor} is a fractional number and its integer part $int(n_{theor})$ is an even number, then $n_{real} = int(n_{theor}) + 1$;
if $1 \leq k < 2$, then $n_{real} = 1$;
if $k \geq 2$, then $n_{real} = 0$.

Although the algorithm looks rather complicated, it allows us to correctly determine the values of n_{real}. Table 2 shows the results of calculating n_{theor} and n_{real} for different values of parameter k, and Figure 3 shows the points where one train meets all the trains travelling towards it. For each such encounter, a siding must be used. Only if the inter-train interval τ_{int} is twice or more than the value of τ_{path}, the trains will not meet at the considered section. This case is illustrated by the variant $k = 2$ shown in Figure 3. The value of n_{real} can only take odd values, because trains enter the line in pairs, and the number of sidings must be one less than the number of trains simultaneously on the section.

Table 2. Calculation results of n_{theor} and n_{real}

k	1.2	1.1	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
n_{theor}	1.67	1.81	2.0	2.22	2.5	2.86	3.33	4.0	5.0	6.67	10	20
n_{real}	1	1	1	3	3	3	3	3	5	7	9	19

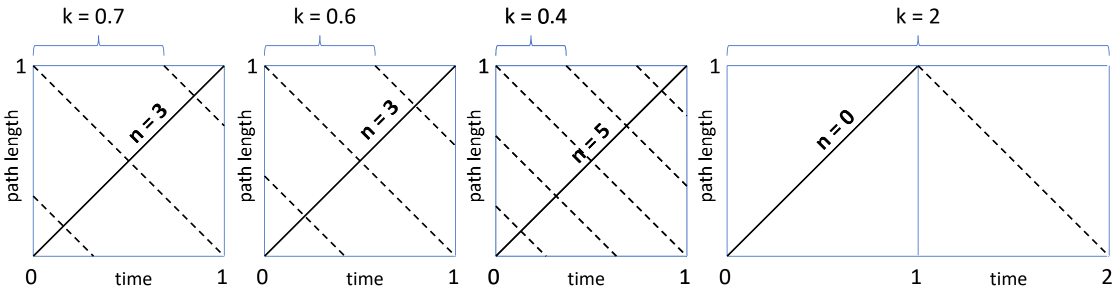

Figure 3. Meeting points of one train with oncoming trains

This model is used to prepare the data for the simulation model. The approximate number of sidings is determined depending on the length of the line, the average technical speed of the train and the number of pairs of trains per day. For example, with $l_{path} = 120$ km and $v_{path} = 50$ km/h 12 pairs of trains per day can be specified. This means that $\tau_{path} = 2.4$ h, $\tau_{int} = 2$ h, $k = \frac{2}{2.4} = 0.83$, $n_{theor} = 2.4$ and $n_{real} = 3$. The required number of sidings is three.

4. Development and application of the simulation model

The simulation model of container trains travelling along the routes shown in Figure 2 was created using AnyLogic simulation software.

4.1. Characteristics of the built model

To build the model, a process modelling paradigm called "agent-based" was applied. The logic of train movement along the routes is shown in the state diagram of an agent of Train type (Figure 4). The numerical parameters of train movement along a particular track and the total time of travelling along the track are calculated using appropriate programs written in Java programming language. Other programmes calculate the delay time at stations using an exponential distribution with a shift.

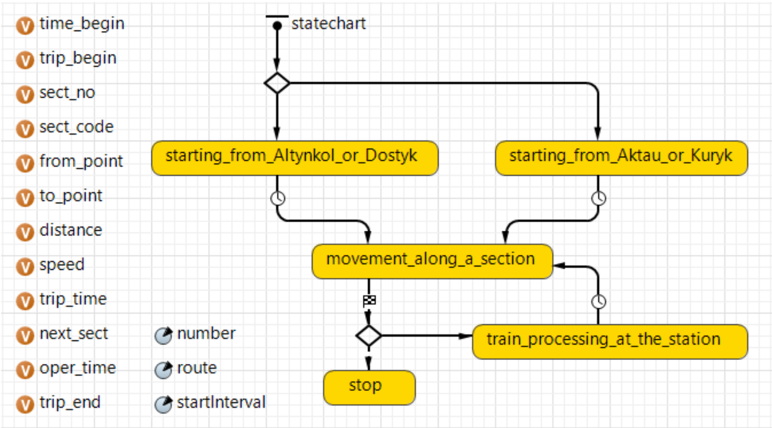

Figure 4. State diagram of the Train type agent

As mentioned above, the "delay at end point" parameter shown in Table 1 is used as the mathematical expectation of the distribution of train handling times. For all operations, the same construct is applied to obtain numbers corresponding to an exponential distribution with a shift. It is assumed that the left boundary of the distribution, i.e. the shift, corresponds to a time that is 30% shorter than the average duration of the operation, and the calculated exponential distribution parameter ensures that the given average duration of the operation is maintained. When using such a design, most often an operation will have a duration close to the specified average value, but sometimes this duration will be significantly higher than this value, which is quite consistent with the situations at real stations.

In the model, a database is created based on an external Excel program, with the help of which both input of initial data is carried out, for example, in the form of Table 1, and output of simulation results. Figure 2 shows a fragment of the animation seen by the user of the model. The flags display the delay time of the train at the next station it reached while moving along the route.

4.2. Design and results of experiments with the model

In the experiments with the model two routes were investigated: Altynkol – Aktau-Port and Dostyk – Aktau-Port. As mentioned above, the main output of the model is the trip time along the route. This time depends on the average physical speed of the train, as well as scheduled delays at stations and possible delays at sidings. It is the influence of this factor that was investigated in the model experiments described below. It was assumed that the container train has maximum priority and passes all sidings without delays (the "without sidings" variant) and stops only at stations. In the second case, the train is delayed randomly at about 50% of all sidings (the "with 50% sidings" option). Finally, the "with 100% sidings" option was investigated, where the train is delayed at each siding.

The movements along each route for all three pass options were simulated 100 times. The main numerical results of the simulation are shown in Table 3, and Figures 5 and 6 show the histograms of trip time distribution for both routes.

Table 3. Simulation results of two routes for container trains

Route	Distance (km)	Average physical speed (km/h)	Net movement time (h)	Number of sidings	Average trip time without sidings (h)	Average trip time with 50% sidings (h)	Average trip time with 100% sidings (h)
Altynkol – Aktau-Port	3106.1	50	62.1	25	69.2	74.5	79.1
Dostyk – Aktau-Port	3640.2	50	72.8	30	81.1	87.1	93.1

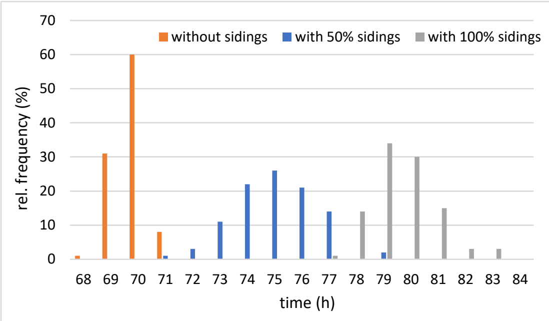

Figure 5. Histogram of trip time distribution for route "Altynkol – Aktau-Port"

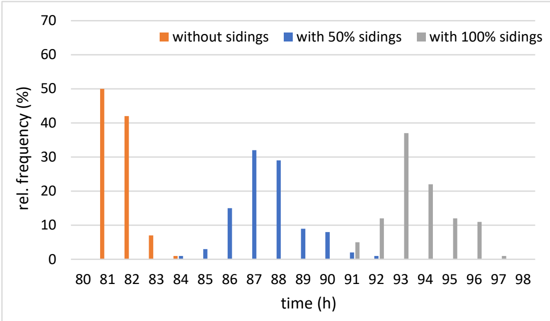

Figure 6. Histogram of trip time distribution for route "Dostyk – Aktau-Port"

5. Conclusion

The impact of sidings on the trip time along the route is very significant. The difference between "without sidings" and "with 100% sidings" is 10 hours for the shorter route and 12 hours for the longer route, which is 16% of the net movement time. The modelling results prove by numbers the necessity to apply well-known ways to reduce the influence of sidings on travel time: replace single-track sections with double-track sections and create a sufficient number of sidings on single-track sections. In the latter case, the journey time of a container train can be reduced only if it has priority right of way at sidings, as is often done for passenger trains. The model can be applied to assess the effect of railway route infrastructure changes that are in the planning stage or have already been implemented but are not yet reflected in the current version of the model.

It is known that the bottleneck in the transport corridor under consideration is the border departure stations of container trains, where a large number of containers accumulate. Computer simulation is an effective tool for analysis and optimisation of such logistics facilities, which are often called "dry ports". It can be used to evaluate the effects of introducing new technical means and technologies for container storage and transshipment. The model can be built for any specific station where container flows are handled, and such a model can be the next stage of the simulation study conducted by the authors of this paper.

References

1. Amorim, G. A., Lopes, L. A. S. and Silva Junior, O. S. (2020) Discrete event-based railway simulation model for eco-efficiency evaluation. *International Journal of Simulation Modelling*, 19(3), 375–386. Available: https://doi.org/10.2507/IJSIMM19-3-517.
2. CAREC. (2017) Unlocking the potential of railways: A railway strategy for CAREC, 2017–2030. Mandaluyong City, Philippines: Asian Development Bank, 2017. Available: http://dx.doi.org/10.22617/RPT178656-2.
3. CAREC. (2021) Railway sector assessment for Republic of Kazakhstan. Central Asia Regional Economic Cooperation (CAREC), ADB, 2021. Available: https://www.carecprogram.org/uploads/CAREC-CRA-KAZ_7th_4MAR2021_WEB.pdf.
4. Cui, Y., and Martin, U. (2011) Multi-scale simulation in railway planning and operation. *PROMET – Traffic & Transportation*, 23(6), 511–517. Available: https://hrcak.srce.hr/file/122067.
5. Cui, Y., Martin, U. and Liang, J. (2018) *PULSim:* User-based adaptable simulation tool for railway planning and operations. *Journal of Advanced Transportation*, Volume 2018, Article ID 7284815. Available: http://dx.doi.org/10.1155/2018/7284815.
6. Divis, R. and Kavicka., A. (2014) Train movement dynamics within Anylogic tool. In: *Proceedings of the 26th European Modeling and Simulation Symposium*, EMSS2014, 307–312. Available: https://www.msc-les.org/proceedings/emss/2014/EMSS2014_307.pdf.
7. Johansson, I., Palmqvist, C.-W., Sipilä, H., Warg, J., and Bohlin, M. (2022) Microscopic and macroscopic simulation of early freight train departures. *Journal of Rail Transport Planning & Management*, 21, 100295. Available: https://doi.org/10.1016/j.jrtpm.2022.100295.
8. Kotenko, A. G., Sattorov, S. B., Nehoroshkov, V. P., and Timuhin, K. M. (2021) Model for forecasting the dynamics and growth of the throughput of the Central Asian transport corridor lines. *Journal of Physics: Conference Series*, 2131, 032102. Available: doi:10.1088/1742-6596/2131/3/032102.

9. Krugman, P. (1991) Increasing returns and economic geography. *Journal of Political Economy*, 99(3), 483–499. Available: pr.princeton.edu/pictures/g-k/krugman/krugman-increasing_returns_1991.pdf.
10. Kumagai, S., Tsubota, K., and Gokan. T. (2021) Corridor developments for transforming Central Asia: a spatial computable general equilibrium model. *Unlocking Transport Connectivity in the Trans-Caspian Region*, edited by D. Azhgaliyeva and Y. Kalyuzhnova. Chapter 7, Tokyo, ADBI, 166-186. Available: https://www.adb.org/publications/unlocking-transport-connectivity-trans-caspian-corridor.
11. Michal, G., Huynh, N., Shukla, N., Munoz, A., and Barthelemy, J. (2017*)* RailNet: A simulation model for operational planning of rail freight. *Transportation Research Procedia*, 25, 461–473. Available: https://doi.org/10.1016/j.trpro.2017.05.426.
12. Moeinaddini, A., Shafahi, Y., and Mohammadhasani, R. (2017) A simulation model for train movements in the rail network. In: *Proceedings of the Institution of Civil Engineers – Transport*, 172(3), 152–163. Available: https://www.icevirtuallibrary.com/doi/abs/10.1680/jtran.16.00082.
13. Nash, A., and Huerlimann, D. (2004) Railroad simulation using OpenTrack. *Computers in Railways IX*, 74, 45–54. Available: https://www.witpress.com/elibrary/wit-transactions-on-the-built-environment/74/12035.
14. Radtke, A., and Hauptmann, D. (2004) Automated planning of timetables in large railway networks using a microscopic data basis and railway simulation techniques. *Computers in Railways IX*, 74, 615–625. Available: https://www.witpress.com/elibrary/wit-transactions-on-the-built-environment/74/12091.
15. Široký, J., Nachtigall, P., Tischer, E., and Gašparík, J. (2021) Simulation of railway lines with a simplified interlocking system. *Sustainability*, 13, 1394. Available: https://doi.org/10.3390/su13031394.
16. Tischer, E., Nachtigall, P., and Široký, J. (2020) The use of simulation modelling for determining the capacity of railway lines in the Czech conditions. *Open Engineering*, 10(1), 224–231. Available: https://doi.org/10.1515/eng-2020-0026.
17. Tolujew, J., Yatskiv, I., Jackson I., and Reggelin, T. (2018) Dynamic model of the passenger flow on Rail Baltica. In: *Proceedings of the 2018 Winter Simulation Conference*, M. Rabe, A. A. Juan, N. Mustafee, A. Skoogh, S. Jain, and B. Johansson (eds.). IEEE Press, 3096-3107. Available: doi:10.1109/WSC.2018.8632549.
18. Watanabe, D., Shibasaki, R., and Arai, H. (2021) Logistics policy analysis and network model simulation for cross-border transport in the Trans-Caspian transport corridor: the global intermodal logistics network simulation model. *Unlocking Transport Connectivity in the Trans-Caspian Region*, edited by D. Azhgaliyeva and Y. Kalyuzhnova. Chapter 8, Tokyo, ADBI, 187–206. Available: https://www.adb.org/publications/unlocking-transport-connectivity-trans-caspian-corridor.
19. Zinser, M., Betz, T., Becker, M., Geilke, M., Terschlüsen, C., Kaluza, A., Johansson, I., and Warg, J. (2019) PRISM: A macroscopic Monte Carlo railway simulation. In: *Proceedings of 12th World Congress on Railway Research (WCRR)*, Tokyo, Japan. Available: https://www.diva-portal.org/smash/record.jsf?pid=diva2%3A1475375&dswid=-5154