O 7. TRANSPORT CAPACITY ASSESSMENT FOR TRAINS USING SIMULATION TECHNIQUE

Mehmet Sinan Yıldırım[1*], Metin Mutlu Aydın[2]

[1]*Manisa Celal Bayar University, Manisa, Turkey*
[2] *Ondokuz Mayıs Üniversitesi, İnşaat Mühendisliği, Samsun*

E-mail: *msyildirim35@gmail.com*

ABSTRACT: Trains are employed for efficient and economic freight and passenger transport between freight centers and station such a dry port, logistic villages, seaports and cities. The preliminary step of planning a railway transport network is the capacity assessment of the transport system for the freight and passenger throughput. Unfortunately, this step requires a detailed study of the underlying transport network and infrastructure. In this study, a novel microscopic simulation model is introduced to evaluate the transport capacity of train services using the discrete event microsimulation (DES) paradigms. A hypothetical railway section, infrastructural and operational constraints are considered in the scope of different train interarrival scenarios. With the microscopic simulation model, the variation of the freight transport capacity is investigated for a set of model variables and operational constraints. The results of the study indicate that, while the hourly train output remains same, the stochastic and constant train arrival patterns may disturb the line capacity differently. This study demonstrates the applicability of the microsimulation models for railway capacity assessment considering delays and number of train stops.

***Keywords**: Railway, microsimulation, capacity, transport, throughput*

1. INTRODUCTION

With the emergence of intermodal transport, increase of the trade throughput and passenger numbers, the issue of how to evaluate the capacity of railway transport systems has been gaining intensive attention. To evaluate the railway transport capacity, it is necessary to develop a systematic capacity evaluation tool. The capacity evaluation for the transport systems generally relies on analytical methods, mathematical models or the computer simulation approaches (Pouryousef and Lautala, 2015). The problem of capacity evaluation especially rises from the complexity of the underlying system. Because of this high complexity and unpredictability involved in railway operations, it is often technically problematic to implement the analytical and mathematical models to evaluate the capacity. Therefore, simulation methodology has been generally used to evaluate the railway capacity for microscopic and macroscopic levels.

The main objective of this study is to propose a comprehensive discrete-event microsimulation (DES) model that can be used for evaluating the railway transport capacity of a specific corridor and also conduct a hypothetical what-if scenarios to test the efficiency and reliability of the model. A summary of the literature required for the study and the purpose of the study are in Introduction section. In the existing literature, both theoretical and practical capacity concepts are used. The latter one is especially calculated with the realistic measures such as operational quality and reliability (Abril et al., 2008). In the scope of the analytical models, the railway environment is modelled using the mathematical expressions and relations. Unfortunately, the analytical models represent the system roughly and theoretical capacity assumptions are reached using these tools. The UIC compression method, developed by the International Union of Railways is a well-known technique which uses the train timetable compression to calculate a theoretical operational capacity (*UIC*, 2013).

Beside the pure analytical models, the optimization methods are also utilized to solve the railway capacity problems with focusing on the train timetable. Among them, Szpigel (1972) firstly implemented to a branch-and-bound algorithm for train scheduling considering a single railway track using the train departure times. The optimization problems are also handled using the mixed integer linear programming (Jovanović and Harker, 1991; Zhang and Li, 2019) and heuristics (Carey and Lockwood, 1995; Mu and Dessouky, 2011; Cacchiani et al., 2012). During the last decade, with the advances of the computer capabilities, simulation methods are emerged as an alternative way of evaluating the railway capacity (Lu et al., 2004). Several examples of the railway simulation modelling are conducted to calculate the system performance and capacity of the urban railway systems (Wales and Marinov, 2015), evaluation of the timetable for the capacity and economy (Warg and Bohlin, 2016), train timetable and conflict evaluation (Högdahl et al., 2019) and rail freight capacity evaluation (Cacchiani et al., 2010).

2. MATERIAL AND METHOD

A computer simulation is an attempt to model a real-life or hypothetical system on a computer to study how the system works (Yıldırım et al., 2020). Computer simulation is generally used as a substitute for an underlying system without and simple analytic solutions. DES is often used which manages the events at discrete time moments. In the concept of the DES, the simulation engine upholds a list of scheduled events synchronized by the simulation engine clock. The simulation engine reads the queue and triggers synchronized events. In the scope of the DES methodology, system state modifications and decision makings only took place at the discrete times. Simulation models can also handle the stochastic behavior and randomness of the underlying systems. Stochastic simulation engine generates stochastic numbers with using a specialized random number generator for seeding the random variables. Specific stochastic distributions are also used to represent the stochastic characteristics of the underlying system.

To simplify the railway operations in a specific railway corridor, several simplifications are made following the conceptual planning stage. The most important assumption is that, there is no overtaking for the trains. The no-overtaking assumptions significantly simplifies the railway operations and priority problems associated with the seizing of the railway line track resources. Moreover, the operated trains are assumed to cruise the same average speeds within same railway line segments. The simulation model primarily based on the synchronized allocation of the railway track resources, routing delays and release of the associated resources. During this procedure, following trains try to seize the track resources prior to the track release and the railway operations is performed with successive railway track modules. In this study, Arena software is used as the simulation modelling framework. The utilized Arena modules are shown in Figure 1.

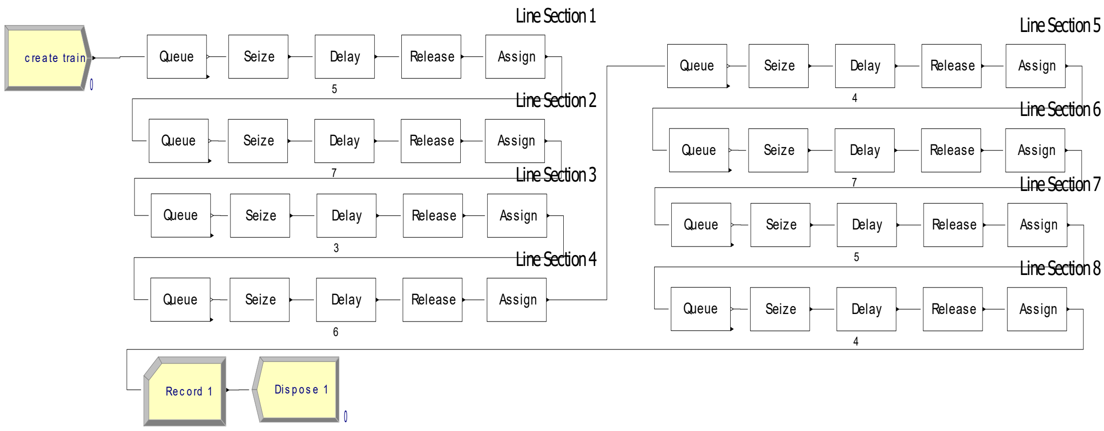

Figure 1. Arena module for a single railway track operation

In the Figure 1, the queue block is used for train waiting for the seize of the next railway track resource, seize block is used to seize the railway track resource and release block is used to release the already seized railway track resource. The delay block is issued for representing the train routing delay through a line track section. Each train is generated from the create block with a predetermined interarrival time and it routes through the successive connected block as a moving system entity. The assign block is used for recording the operational statistics of the trains as the waiting delay (minutes) for seizing the next resource and the total number of train stops through the operation. The cumulative train statistics are used for calculating the average train delay (minutes) at the queue and average number of train stops for evaluating the scenario performances.

The hypothetical railway corridor consists of 8 line track sections with a total routing time of 44 minutes. The routing time of the line track sections are considered same for the trains. Each line track section is designed as bi-directional. The train routing times of the sections are 5,7,3,6,4,7,5 and 7 minutes from the first to the last section. The conceptual drawing of the railway line sections is shown in Figure 2.

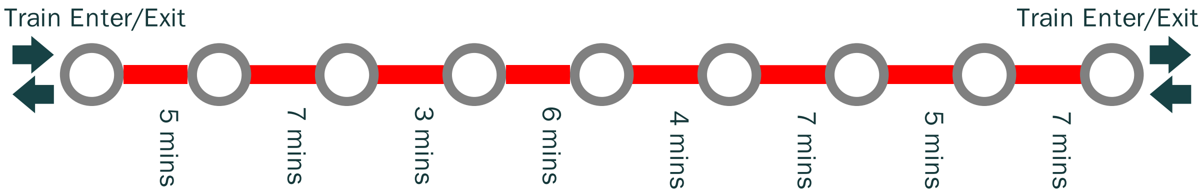

Figure 2. Conceptual drawing of the railway line sections and train routing times

3. RESEARCH FINDINGS

The simulation model is executed for different train interarrival scenarios. The execution time was 24 hours corresponding a daily schedule. For evaluating the train operational disruptions, also another stochastic train arrival scenario is prepared for assuming that train interarrivals suits with the exponential distribution. In fact, this scenario is not realistic because the trains usually operate with a specific train timetable and predetermined train schedules and any disruptions need to be corrected as soon as possible. The stochastic arrival scenario is executed for 50 replications and the average values of the performance measures are taken with the associated confidence intervals. The execution results of the constant and stochastic train arrival scenarios are given in Table 1.

Table 2. Scenario execution outputs for the constant and stochastic train arrival scenarios

Train Interarrival Time	Constant Interarrival RN=1			Stochastic Interarrival RN=100		
	Number of Generated Trains	Avg. Train Waiting Delay (min.)	Number of Train Stops	Number of Generated Trains	Avg. Train Waiting Delay (min.)	Number of Train Stops
4 hr.	12	0	0	14.02 (±1.13)*	0	0
2 hr.	24	1.8	8	25.76 (±1.31)	2.34	11.2 (±6.4)
1 hr.	48	3.1	14	48.92 (±1.96)	3.86	16.7 (±8.12)
30 min.	96	8.4	39	97.7 (±3.14)	11.21	44.16 (±9.2)
15 min.	192	21.54	138	191.02 (±4.14)	19.27	198.31 (±18.11)

Note=RN shows replication number: *95% confidence interval on expected values

According to the results in Table 1, the following conclusions can be made If the train interarrival times decrease, the average train waiting delays and number of train stops are increased as expected. However, for the 4 hours of train interarrival time, no congestion issue is observed for the constant and stochastic interarrival scenarios. For the stochastic interarrival scenario, increased average waiting delays and number of train stops were observed. Additionally, the confidence intervals are larger for the stochastic interarrival scenarios because of higher variability of the train interarrivals and more frequent train conflicts. With the direct examination of the model execution, we can conclude that the stochastic generation of the trains also disturbs the train routing operation. Also, it can be found that several distinct times cause a decrease in train interarrival samples between successive trains and it results larger train blockages and delays.

4. CONCLUSION AND DISCUSSION

In this study, a discrete event simulation methodology is demonstrated for evaluating the operational capacity of a railway corridor. The railway network is modelled using a DES model resources. The entity delay blocks are used for resource allocation using a systematic approach. It is obtained from the analysis results that the developed methodology can be used for evaluating the railway capacity of a hypothetical railway corridor with double railway track segments and various train interarrival distributions. Study findings can be a good example for train transport capacity assessment for freight trains. Hence, planners can be used the suggested method in the study for planning process.

REFERENCES

Abril, M., Barber, F., Ingolotti, L., Salido, M.A., Tormos, P., Lova, A., 2008, An assessment of railway capacity. *Transp. Res. Part E Logist. Transp. Rev.* 44, 774–806. https://doi.org/10.1016/j.tre.2007.04.001

Cacchiani, V., Caprara, A., Fischetti, M., 2012, A Lagrangian Heuristic for Robustness, with an Application to Train Timetabling. *Transp. Sci.* 46, 124–133. https://doi.org/10.1287/trsc.1110.0378

Cacchiani, V., Caprara, A., Toth, P., 2010, Scheduling extra freight trains on railway networks. *Transp. Res. Part B Methodol.* 44, 215–231. https://doi.org/10.1016/j.trb.2009.07.007

Carey, M., Lockwood, D., 1995, A Model, Algorithms and Strategy for Train Pathing. *J. Oper. Res. Soc.* 46, 988. https://doi.org/10.2307/3009909

Högdahl, J., Bohlin, M., Fröidh, O., 2019, A combined simulation-optimization approach for minimizing travel time and delays in railway timetables. *Transp. Res. Part B Methodol.* 126, 192–212. https://doi.org/10.1016/j.trb.2019.04.003

Jovanović, D., Harker, P.T., 1991, Tactical Scheduling of Rail Operations: The SCAN I System. *Transp. Sci*. 25, 46–64. https://doi.org/10.1287/trsc.25.1.46

Lu, Q., Dessouky, M., Leachman, R.C., 2004, Modeling train movements through complex rail networks. ACM Trans. Model. *Comput. Simul.* TOMACS 14, 48–75. https://doi.org/10.1145/974734.974737

Mu, S., Dessouky, M., 2011, Scheduling freight trains traveling on complex networks. Transp. Res. Part B Methiodal. 45, 1103–1123. https://doi.org/10.1016/j.trb.2011.05.021

Pouryousef, H., Lautala, P., 2015, Hybrid simulation approach for improving railway capacity and train schedules. J. Rail Transp. Plan. Manag. 5, 211–224. https://doi.org/10.1016/j.jrtpm.2015.10.001

Szpigel, B., 1972, Train scheduling, Doctoral dissertation thesis, Pontificia Universidade Catolica of Rio de Janeiro, Brazil.

UIC, Capacity (No. 2), 2013, UIC International Union of Railways, France.

Wales, J., Marinov, M., 2015, Analysis of delays and delay mitigation on a metropolitan rail network using event based simulation. Simul. Model. Pract. Theory 52, 52–77. https://doi.org/10.1016/j.simpat.2015.01.002

Warg, J., Bohlin, M., 2016, The use of railway simulation as an input to economic assessment of timetables*. J. Rail Transp. Plan. Manag.* 6, 255–270. https://doi.org/10.1016/j.jrtpm.2016.08.001

Yıldırım, M. S., Aydın, M. M., & Gökkuş, Ü., 2020, Simulation optimization of the berth allocation in a container terminal with flexible vessel priority management. *Maritime Policy & Manag.*, 1-16.

Zhang, X., Li, L., 2019, An Integrated Planning/Pricing Decision Model for Rail Container Transportation. *Int. J. Civ. Eng.* 17, 1537–1546. https://doi.org/10.1007/s40999-019-00420-7