A SIMULATION MODEL FOR LIGHT RAIL TRANSPORTATION SYSTEM

Filiz Dumbek[(a)], Dilay Celebi[(b)]

[(a)(b)]Department of Management Engineering, Istanbul Technical University, Macka 34367, Istanbul, Turkey

[(a)]dumbek@itu.edu.tr, [(b)]celebid@itu.edu.tr

ABSTRACT
Public transportation has a strategic importance especially in large cities with respect to increasing population. Subway and light rail systems are efficient passenger transportation systems in large cities due to their large capacities and they are usually faster than other transportation tools. Increasing demand for these transportation systems has brought up the use of complex models to increase efficiency of the system by reducing time delays and passenger waiting times. In this study, a simulation model has been developed to determine best operation strategy in Istanbul Light Rail Transportation System (LRTS). Currently, Istanbul LRTS network has 18 stations and a total length of 19,6 km. This network provides transportation service for 240.000 passengers every day and operates according to predefined timetables which differ due to the operating season and day of the week. The system was developed as a discrete event simulation model and Arena Simulation Software was used.

Keywords: simulation, light rail transportation, passenger service quality

1. INTRODUCTION

Efficient management of rail systems that presents an effective solution for the big cities which are getting crowded day by day is very important in terms of operational efficiency and passenger service quality.

Public rail transportation planning process has been divided into strategic, tactical and operational levels (Ghoseiri, Szidarovszky, and Asgharpour 2004). Demand analysis and line planning are considered in the strategic planning level. Rolling stock planning, crew scheduling, crew rostering are considered in the tactical planning level. Train scheduling that includes departure times of the trains for specified routings take place between tactical and strategic planning levels. Therefore, scheduling process of the trains has significant importance to provide operational efficiency and passenger service quality.

Hooghiemstra and Teunisse (1998) indicate that travel times and halting times, plus possibly a maximum travel time between the end stations, constrain the timetable of an individual train.

While timetables are being constructed, service quality of the system should be taken into consideration. Vansteenwegen and Oudheusden (2007) indicate that passenger waiting time is a critical factor to evaluate passenger service quality.

Yalcinkaya and Bayhan (2008) developed a model optimize average travel time for a metro line by using simulation and response surface methodology. Headways which represent time interval between two consecutive trains were calculated to find optimum rate of carriage fullness and average travel time (Yalcinkaya and Bayhan 2008).

In this study, a simulation model was developed to determine optimum process strategy in Istanbul Light Rail Transporation System (LRTS). This network was founded in 1989 and been expanded over years. Currently, Istanbul LRTS network has 18 stations and total length of 19,6 km. This system has different time tables on weekdays, Saturdays, and Sundays.

2. SYSTEM STRUCTURE

Istanbul LRTS was founded in 1989 and currently has 18 stations. Istanbul Ulasim Corporation has 92 wagons and 80 of these wagons are being used. 17 vehicles operate in network and network has 240.000 passenger transport capacity per day. Figure 1 shows the rail network of Istanbul city. Red colored network indicates Istanbul light rail transportation system.

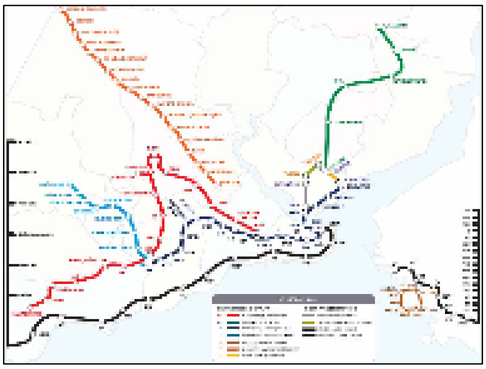


Figure 1: Istanbul Rail Network

In developed model seven stations (Aksaray, Emniyet, Ulubatli, Bayrampasa, Sagmalcilar, Kartaltepe, Otogar) of this network were taken into consideration. System operates between 5:00 am and 1:00 am.

Simulation model was developed to reflect system structure according to these predefined constraints.

1. Number of vehicles
2. Minimum signalization time between train arrivals for one direction
3. Wagon capacity
4. Minimum train dwell times at stations
5. Minimum transfer time between two stations
6. Vehicle velocity

Currently 17 trains operate in LRTS. One of these trains have used for ring services between two stations and this movement of trains were not included in model. Therefore, 16 trains will operate between specified stations.

Signalization system that is used in the system allows train arrivals with minimum 2 minutes time intervals.

One wagon has 257 passengers carriage capacity. A vehicle operates with four wagons and total passenger carriage capacity is 1028.

Trains stop in stations for passenger alighting and boarding activities at the stations. Dwell times of the trains change according to the station, predefined time intervals during a day and train trip directions.

Minimum transfer times depend on train velocity and the distance between stations. Train velocities can change between stations but average velocities were used. Velocities of the trains did not change during the model. Therefore transfer times between stations have been defined constant according to the current data taken from Istanbul Ulasim Corporation.

3. METHOD

Rail network is a dynamic system that changes during time and variables in this system change at discrete times. Therefore, model was developed as discrete simulation model.

By taking system structure into consideration related data was collected as indicated in section 3.1.

Arena simulation software package was used to developed model and this model based on basic assumptions which are indicated in section 3.2. Section 3.3. explains the used Arena components and section 3.4. explains the model events which are occuring in the system.

3.1. Data Collection

Passenger arrival patterns were defined according to the collected data at stations within 15 minutes intervals between January 2008 and November 2008. Approximately half million records were loaded to Oracle database. Records that represent weekday arrivals to the stations were taken into consideration and average number of the passenger arrivals within 60 minutes was obtained.

Istanbul Ulasim Corporation conducted a survey to obtain percentages of alighting passenger at the stations. Table 1 shows the obtained results from this survey. For example, it was shown that %4,9 of passengers who starts their trip from Aksaray station alight at Emniyet station. This information was used to update the number of the passengers in the train and train's current capacity was calculated after this update.

Table 1: Percentages of Alighting Passengers at the Stations

		Trip Starting Station																	
		Aksaray	Emniyet	Ulubatli	Bayrampasa	Sagmalcilar	Kartaltepe	Otogar	Esenler	Terazidere	Davutpasa	Merter	Zeytinburnu	Bakirkoy	Bahcelievler	Atakoy	Yenibosna	DTM	Havalimani
Trip Ending Station	Aksaray	0	6.1	4.5	16.1	35.1	27	20.6	28.8	22.7	19	21.4	4.5	9.7	0	14.5	10.8	12.5	15.6
	Emniyet	4.9	0	4.5	3.2	8.1	5.4	4.4	7.7	9.1	0	7.1	1.5	3.2	4.8	4.3	3.6	0	0
	Ulubatli	1	0	0	0	2.7	2.7	2.9	1.9	0	4.8	0	1.5	3.2	4.8	2.9	4.8	0	0
	Bayrampasa	11.7	12.1	0	0	0	0	7.4	3.8	0	9.5	28.6	3	12.9	9.5	13	13.3	0	9.4
	Sagmalcilar	6.8	15.2	9.1	0	0	5.4	5.9	3.8	0	0	14.3	3	6.5	4.8	8.7	8.4	0	3.1
	Kartaltepe	9.7	3	4.5	9.7	0	0	4.4	5.8	0	4.8	0	4.5	9.7	4.8	4.3	4.8	0	0
	Otogar	15.5	3	4.5	6.5	5.4	5.4	0	5.8	0	9.5	7.1	9.1	6.5	0	8.7	10.8	12.5	9.4
	Esenler	13.6	21.2	22.7	9.7	13.5	5.4	5.9	0	0	0	0	7.6	6.5	9.5	7.2	12	12.5	6.3
	Terazidere	1	0	0	12.9	5.4	2.7	0	0	0	4.8	0	6.1	6.5	4.8	5.8	2.4	0	0
	Davutpasa	1.9	0	0	3.2	0	8.1	0	0	4.5	0	7.1	0	6.5	0	0	1.2	0	3.1
	Merter	0	3	9.1	3.2	0	2.7	8.8	0	0	0	0	0	0	0	2.9	3.6	0	0
	Zeytinburnu	5.8	9.1	0	3.2	2.7	8.1	4.4	15.4	18.2	4.8	0	0	16.1	23.8	17.4	10.8	12.5	15.6
	Bakırkoy	3.9	3	13.6	6.5	8.1	8.1	1.5	5.8	0	4.8	0	16.7	0	0	0	1.2	0	6.3
	Bahcelievler	1	6.1	0	3.2	5.4	8.1	5.9	1.9	13.6	0	7.1	7.6	0	0	4.3	2.4	12.5	0
	Atakoy	7.8	0	4.5	0	2.7	2.7	11.8	5.8	9.1	33.3	0	19.7	0	14.3	0	1.2	25	9.4
	Yenibosna	9.7	18.2	18.2	12.9	8.1	5.4	11.8	13.5	22.7	4.8	0	10.6	12.9	19	2.9	0	12.5	21.9
	DTM	1	0	0	3.2	0	0	1.5	0	0	0	7.1	0	0	0	1.4	0	0	0
	Havalimani	4.9	0	4.5	6.5	2.7	2.7	2.9	0	0	0	0	4.5	0	0	1.4	8.4	0	0

Current data represents number of passengers that enters to the stations within specified time periods. Destination of any passenger entering the system was assigned based on the probabilities determined through this conducted survey.

3.2. Model Assumptions

Simulation model was developed based on the following basic assumptions:

1. Trains operate on a single unidirectional track.
2. The system is a terminating system and works for predetermined hours of a day.
3. Speeds of the trains are system variables, but they do not change during a trip.
4. Inter-arrival times of passengers are exponentially distributed with rates given in 60 minutes intervals.
5. Dwell times at stations are function of arrival time of the passengers waiting in the station and getting off the train.
6. Only one train is allowed at a time in a station.
7. Passengers wait for trains in stations and get on the train according to the train's current capacity and number of passengers on it.
8. If there is no train to board at departure time due to a delay, passengers go on waiting for a train until train arrives. There will be no adjustment in timetable due to this delay.
9. Trains can follow different routes depending on the schedule. Half routes are allowed.
10. The system represents normal conditions. Failures in railway or trains are not included.
11. Headways are determined before the simulation model is run. Headways can be different for different time intervals, but the headway for a time interval is fixed during the running of the simulation model.

12. Simulation model of the system was developed for seven stations. Other part of the system was taken into consideration by calculating trip times according to the train cycles and adding this time to the delay times in the model.
13. All passengers in the train alight at the terminal stations.

3.3. Model Components

Number of stations, distances between stations, number of trains and their velocities are controllable input variables of the system.

In developed model, these Arena modules were used for modeling the system events: Create, Transporter, Request, Free, Dispose, Station, Assign, Route, Schedule, File, Read/Write, Signal, Hold, Delay, Decide, Separate, Record.

Create module was used to generate passengers at the system according to the defined arrival type schedules according to the collected and analyzed passenger for each station and direction. Also this module was used to direct drivers to start their trips.

Transporters were used to define limited number of trains in the system. Trains start their trips by using of request module and at the end of trips they were released with free module.

Dispose module was used to remove waiting passengers from the stations after the train arrivals.

Signal and hold modules work coordinately in the model. A signal value was sent to the related station after train arrivals and waiting passengers at hold module's queue was released and disposed.

Stations represent the predefined seven stations at the system. System was developed as a circle network and one station was defined as two stations in Arena model that represents different directions of train movements at the stations. Table 2 represents the defined stations in the model.

Table 2. Defined Stations in Developed Model

Station	Station Short Name	Station Code	Station Type
Aksaray Start	AKS Start	St0	Station
Aksaray	AKS1*	St1	Station
Emniyet	EMT1*	St2	Station
Ulubatli	ULU1*	St3	Station
Bayrampasa	BAY1*	St4	Station
Sagmalcilar	SAG1*	St5	Station
Kartaltepe	KRP1*	St6	Station
Otogar	OGA1*	St7	Station
Otogar Start	OGA Start	StA0	Station
Otogar	OGA2**	StA7	Station
Kartaltepe	KRP2**	StA6	Station
Sagmalcilar	SAG2**	StA5	Station
Bayrampasa	BAY2**	StA4	Station
Ulubatli	ULU2**	StA3	Station
Emniyet	EMT2**	StA2	Station
Aksaray	AKS2**	StA1	Station

* These stations are used for the trips at Otogar direction.
* These stations are used for the trips at Aksaray direction.

Assign module was used to make assignments or changes in system variables and attributes according to the defined equations.

Route module was used to transfer trains between stations at specified times.

Train schedules were determined outside of the system and train trip start times and directions were read from a predefined file. Separate module generates a new entity to read next departure while the entities were starting their trips.

Train dwell times at stations were kept at delay module.

Decide module was used to control signalization time factor and only trips that have minimum 2 minutes was allowed to start trips as shown in the first expression otherwise they waited until the minimum time interval was provided as shown in the second equation.

Terminal Station Departure Time >= Previous Departure Time + 2 (1)

Delay Time = 2 – (Terminal Station Departure Time – Previous Departure Time) (2)

Record module keeps the time between arrival statistics of passengers at each station and time between arrival statistics of trains for terminal stations.

Furthermore these attributes and variables were defined in the developed model:

3.3.1. Attributes

Attributes are used to attach specific values to the entities that can differ from one entity to another. In developed model these attributes were defined:

Train capacity: '1028' was assigned in the beginning of trips.

Number of passenger in the train: '0' was assigned in the beginning of trips and this value was updated at stations according to the number of passengers that got on the train at this station.

Number of alighting passengers in specified stations: Number of boarding passengers was multiplied by percentages of alighting passengers for the next stations and attributes were assigned.

Trip start time: Specified timetables include train trip start times for the terminal stations. This attribute kept these start times and it was used in delay module to define required waiting time as difference between assigned trip start time and system time.

Train route: Developed model allows defining various routes for different requirements. At terminal stations this attribute was assigned and it was controlled at defined decision points.

3.3.2. Variables

Variables are used to reflect the state of system for specific purposes and they are not attached to the entities. In developed model these user defined variable were defined:

Number of waiting passengers at stations: This variable was increased with per passenger arrival and decreased after train arrivals to the stations. Number of waiting passengers at stations was updated after boarding of passengers to the trains as the difference between number of waiting passengers and number of boarding passengers.

Number of boarding passengers at stations: Trains have limited capacity to transfer passengers between stations. Number of boarding passengers at stations depends on available capacity of trains and the number of waiting passengers at stations. Minimum value of number of waiting passengers and available capacity of trains gave the number of boarding passengers.

Planned departure time from terminal stations: Signalization system necessitates controlling minimum time interval between departures. This variable was defined for both Aksaray and Otogar stations which are terminal stations in the system. Planned train departure time was kept in this variable.

Actual departure time from stations: This variable was used to keep the actual departure time from stations after required controls were done. Trains started their trips without any delays if difference between planned departure time and actual departure time is greater than or equal 2 minutes. Otherwise, trains departures were delayed to provide required time interval.

3.4. Model Events

Simulation model development was divided into 8 main events and these events were taken into consideration.

1. Trip startings are declared to the drivers. This event occurs according to the pre-defined timetables.
2. Drivers request the nearest train based on the smallest distance rule. Available trains are matched with drivers. If there are no any available trains, drivers will wait until trains become available.
3. Trains arrive to the stations within specified duration. These durations were obtained from Istanbul Ulasim Corporation based on previous data collections.
4. Passengers alight from the train. Number of passengers that alight at the station are determined by previously assigned attribute with these equations. The second equation is repeated until all previous stations' data was evaulated. ANINT function of Arena was used to define number of passengers as integer values.

*No. of alighting passengers at Station X = ANINT (No. of boarding passengers at beginning station * Alighting passenger ratio for station X)* (3)

No. of alighting passengers at Station X = No. of alighting passengers at Station X + ANINT (No. of boarding passengers at the second station in the train direction Alighting passenger ratio for Station)* (4)

5. Trains delay at stations for alighting and boarding activities. Delay times were obtained from Istanbul Ulasim Corporation based on previous data collections for the stations.
6. Passengers arrive to the stations and number of the waiting passengers increases.

No. of passengers at the station at the station = No. of passengers at the station at the station + 1 (5)

7. After the train arrivals, passengers get on the train and number of waiting passengers in the station decreases according to the train capacity. Following equation was used to provide this. MN function of Arena was used to get the minimum value of the available passenger capacity in the train and number of passengers at the specified stations.

No. of alighting passengers = MN ((Capacity – No. of passenger in the train), No. of passengers at the station at the Station X) (6)

8. In Aksaray station trains' route may vary due to the passenger demand and some trips are kept shorter. Routings of the trips are assigned with departure times in the beginning of the trips. Also, according to the last departure time from the terminal stations trains may be freed. Following expression was used to control this in decide module:

TNOW <= Last departure time (7)

TNOW represents the system time and increments during simulation run. Until TNOW is greater than last departure time, trains leave stations; otherwise they are freed.

Appendix A shows the structure of developed Arena simulation model.

4. EXPERIMENTATION

The model is verified by developing the model in a modular manner, using random debug points, substituting constants for random variables, manually checking the results, extreme case analysis, and animating the system.

Experiments were designed to provide a structured framework that explains simulation execution logic in terms of model components. Experimental design provides an estimation how changes in input factors affect the results, or responses of the experiment (Kelton 2000).

Scenario analyses have been conducted on the developed model. Developed model was validated with designed controlled experiments. Passenger arrivals, train schedules and number of trains that operates in railways was defined as parameters and experiments were performed on the developed Arena simulation model. Model was executed within 1200 minutes replication length and model was replicated 40 times. Base time unit was defined as minutes.

In current system, trains are scheduled more frequenet in morning hours. Firstly, current system's average passenger waiting times have been found for spesified stations. Experiments have been conducted with 3, 5 and 10 minutes train arrival intervals. Figure 2 indicates the average passenger waiting times by changing train arrival frequencies.

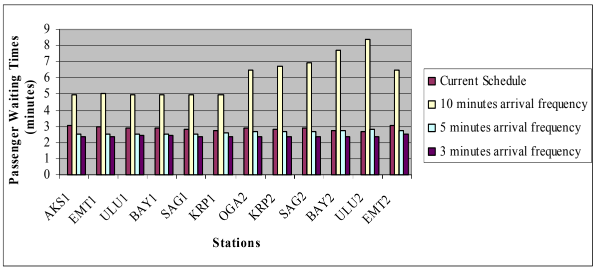


Figure 2: Average Passenger Waiting Times for Different Timetables

It was observed that decrease in headways cannot provide expected decrease in average passenger times without changing number of trains in some cases. 3 minutes time interval between trains' arrivals cannot be implemented with current capacity, 3,894 minutes average time between arrivals was measured in terminal stations.

In current system, there exists 17 trains active and 16 of these trains operate between defined 7 stations in the model. Current schedule has been used in experiments that number of trains have been changed as 5, 10, 20 and average passenger waiting times were observed.

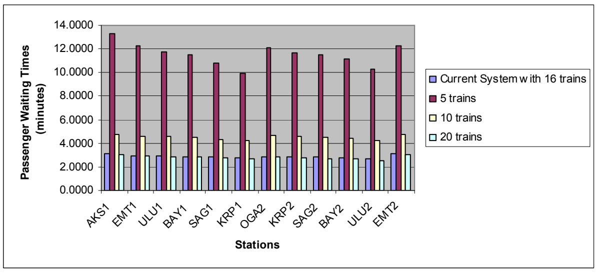


Figure 3: Average Passenger Waiting Times for Different Number of Trains

Increase in the number of trains while current timetables were being implemented did not affect average passenger waiting times. Decrease in the number of trains caused delays in predefined timetable and current table could not be implemented with 10 and 5 trains. Average passenger waiting times have increased due to increase in headways.

5. RESULTS AND CONCLUSION

Developed model was implemented for Aksaray-Havalimani light rail metro system for seven stations. In this study, the number of passengers that are transported in trains and dwell times of the trains in specified stations were analyzed and experiments were made. Passenger waiting times were obtained in the basis of existing system. Changes in the system's performances measures for different conditions were obtained by changing train frequencies and the number of trains in system.

In conclusion, increase in the train arrival frequencies during time periods when passenger arrival rate is high causes decrease in average passenger waiting times. It has been observed that the number of trains is an important factor to implement specified schedules and specified schedules cannot be applied in cases when the number of trains decreases. The simulation model built in this study is a generic model that can be easily changed to adapt the changes in the number of trains and train schedules. By running the model, several what-if questions of operations management can be replied to make revisions. It might also provide suggestions on strategic infrastructure development, and thus provide a starting point for the construction of any new infrastructure, namely capacity planning. It has been observed that the number of trains is an important factor to implement specified schedules and specified schedules cannot be applied in cases when the number of trains decreases.

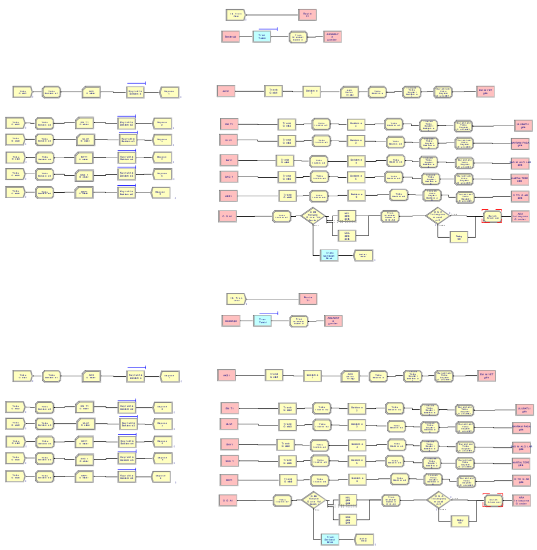
This study represents an efficient tool to measure passenger dwell times in stations by changing the train schedules and feasibility of pre-specified train schedules with by measuring its effect on rail transportation.

6. FUTURE RESEARCH

The scope of the second stage of the research is to expand the model by adding other stations of the network and provide integrity to evaluate the system performance. Also, transfer times between stations will be defined as user defined variable and other possible timetables' effects on the system will be measured.

APPENDIX

APPENDIX A. Developed Arena Model



REFERENCES

Ghoseiri, K., Szidarovszky, F., Asgharpour, M.J., 2004, A multi-objective train scheduling model and solution. *Transportation research*, 38 (10), 927-952.

Hoohiemstra, J.S., Teunisse, M.J.G., 1998. The use of simulation in the planning of the Dutch railway services. *Proceedings of the Winter Simulation Conference*, pp. 1139-1146. December 24-28, Washington (Washington, USA).

Kelton, W.D., 2000. Experimental design for simulation. *Proceedings of the 2000 Winter Simulation Conference*, pp. 32-37. December 10-13, Orlando (Florida, USA).

Vansteenwegen, P., Oudheusden, D.V., 2007. Decreasing the passenger waiting time for an intercity rail network. *Transportation research,* 41 (4), 478-492.

Yalcinkaya, O., Bayhan, G. M., 2008, Modeling and optimization of average travel time for a metro line by simulation and response surface methodology, *European journal of operational research*, 196 (1), 225-233.

AUTHORS BIOGRAPHY

FILIZ DUMBEK graduated from Management Engineering department of Istanbul Technical University in 2009.

DILAY CELEBI is academician of Management Engineering department at the Istanbul Technical University. She received her Ph.D. from Istanbul Technical University in 2008.