Journal of Quality Engineering and Production Optimization

Vol. 7, No. 1, Winter & Spring 2022

http://jqepo.shahed.ac.ir

Research Paper

DOI: 10.22070/JQEPO.2022.15670.1220

A Simulation Model to Estimate the Impact of Self-protection and Social Distancing on the Spread of COVID-19 in the Public Transportation (Case Study: Tehran Metro)

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Abstract *– Metro is one of the most important urban transportation systems in Tehran. Before the pandemic, almost two million trips were made by metro daily. A crowded metro is one of the most important sources of the outbreak. In this paper, a discrete event model is introduced to simulate the spread of the COVID-19 in Tehran metro. Three types of passengers are defined: Healthy passengers and infected passengers with acute conditions and not acute conditions. Two important ways of preventing virus transmission are self-protection (e.g., wearing a mask) and social distancing. Different scenarios of social distancing and self-protection are surveyed based on multiple replications of the proposed model. Results of the simulation showed that noncompliance with social distancing has an exponentially negative effect on the number of infected passengers. In addition, the compliance of infected passengers with the social distancing and self-protection tips is almost twice important as the compliance of healthy passengers.*

Keywords*– Discrete event simulation, Self-protection, Social Distancing, COVID-19, Metro.*

I. INTRODUCTION

Many countries in the world recorded a number of daily coronavirus cases since the pandemic began. The number of patients is increasing every day. To date (May 15, 2022) there have been more than 521 Million confirmed cases of the disease, including more than 6 million deaths in the world. Eastern Mediterranean makes up about 9 percent of the world population, but 12 percent of confirmed cases of the coronavirus. Iran also grapples with the third wave of COVID-19. Iran is one of the most populaces countries in this region and has a significant surge in the number of COVID-19 cases (Figure 1).

Manuscript Received:16- Feb -2022 & Revised: 5- May -2022 & Accepted: 29- June -2022
ISSN: 2423-3781

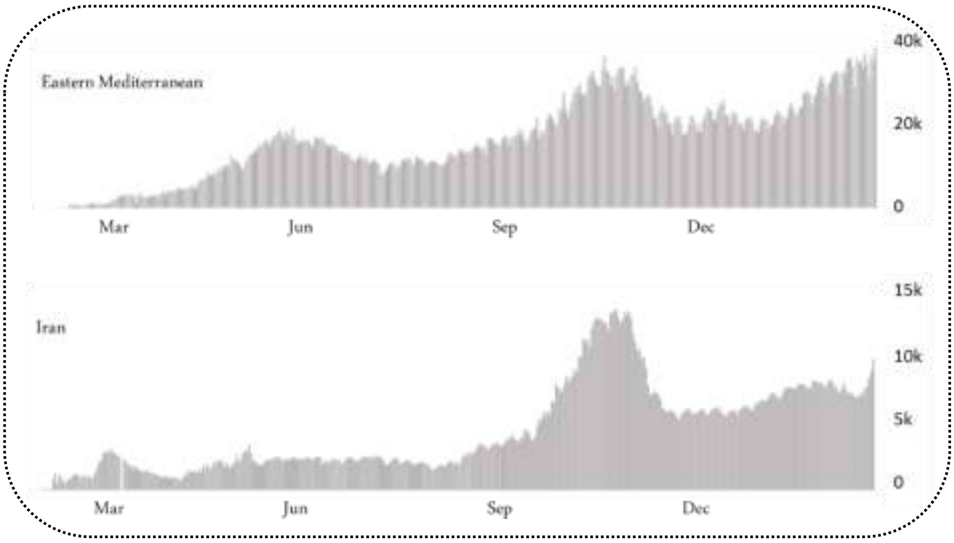

Fig 1. Total number of confirmed cases in Eastern Mediterranean and Iran (Source: WHO)

There are two different views on the transmission of respiratory viruses: airborne versus droplet transmission (Shiu et al., 2019). On the other hand, many people are using the overcrowded metro daily in big cities like Tehran, and thus, it is the main source of virus transmission. In this study, we will analyze the transmission of the virus in the Tehran metro in different situations by using discrete event simulation.

Respiratory virus transmission is a matter of scientific research. Many researchers in the field of epidemiology and medical sciences have studied different related models (such as Richard and Fouchier, 2016; Paytner, 2015). The main strategies to control the transmission of respiratory viruses are social distancing, and wearing a mask (Dzisi and Dei, 2020). The new pandemic and the need to strictly control the transmission of the virus heightened the importance of this topic. Virus transmission in confined and crowded spaces such as public transportation is the main source of the outbreak. An infected person with the COVID-19 virus is contagious before showing any symptoms. It is a worrisome problem in public transportation (Tirachini and Cats, 2020). Several factors could be taken into account on the high risk of virus transmission in public transportation: 1- limited space of public vehicles, 2- scarce access control to identify sick passengers, 3- The existence of multiple surfaces which could facilitate the transmission of the virus (UITP, 2020). Some papers investigated the theoretical transmission mechanism of respiratory viruses in public transportation (Gameiro Da, 2020; Dzisi and Dei, 2020; Hu et al., 2020; Gupta et al., 2012).

Epidemiological modeling of the spread of COVID-19 is a key research topic in computer simulation (Ferguson et al., 2020). Generally, there are three basic approaches to computer simulation modeling: System Dynamics (SD), Discrete Event Simulation (DES), and Agent Based Simulation (ABS).

A system dynamics approach is a simulation method of studying dynamic problems in complex systems characterized by interdependence, mutual interaction, information feedback, and circular causality (Richardson, 2019).

A discrete system can be identified by the discrete state variables (a set of variables that are needed to describe the system at any time) (Banks et al., 2010). DES is a numerical technique to analyze a stochastic discrete system. DES models are typically used to model the systems where entities flow through a number of queues and activities (Currie et al., 2020). DES is a common model used to forecast infectious diseases (Wang and Flessa, 2020).

Agent-based modeling is a computerized simulation of a number of autonomous and heterogeneous agents that interact within an environment based on the prescribed rules. In this approach, individual actions of the agents are combined to produce the system behavior (Badham et al., 2018).

Among different simulation techniques, we used the DES approach to model the spread of coronavirus in a public transportation system as an important source of the outbreak. Discrete characteristics of the system such as passenger's entrance and exit, trip time of passengers, and stochastic nature of virus transmission could be modeled by DES.

The discrete event modeling method considers a system as a sequence of operations being performed across entities. In the metro, a process could be defined as passengers (infected or healthy persons) arriving at the station, then the train arriving, and then starting the trip. In each wagon of the train, healthy and infected passengers are waiting to reach the destination; the transmission occurs during this period. Self-protection and social distancing could alleviate the transmission of the virus.

Social distancing has become the new norm in public transportation (De Vos, 2020). Transit stations played a significant role in spreading influenza in the previous 2009 H1N1 pandemic (Katrakazas et al., 2020). Our observations and governmental data prove that public transportation is the main source of the outbreak (Tirachini and Cats, 2020; Troko et al., 2011). Virus transmission is a dynamic and event-based process that occurs repeatedly in a crowded metro. On the other hand, DES is a simulation approach to simulate dynamic and event-driven system models (Mielke et al., 2019). To the best of our knowledge, there is no research in the literature addressing the benefits of DES to simulate the virus spread in public transportation. In this paper, we will model this stochastic process and the impact of different prevention policies on the virus spread. Currie et al. (2020) and Wang and Flessa (2020) are the previous researchers that highlighted the need of simulating the virus spread in the public transportation.

The rest of this paper is structured as follows: In section 2, the related literature is reviewed. In section 3, DES model is described. In section 4, results of the simulation are provided, and finally, in section 5, some concluding remarks are presented.

II. LITERATURE REVIEW

After the COVID-19 Pandemic, many researchers have been attracted to work on the mechanism of the outbreak with different computer simulation approaches: SD, DES, and ABS. Additionally, some other researchers used hybrid methods.

The spread of the Covid-19 pandemic in the public transportation has been addressed by some researchers. Agent based simulation and system dynamics are the main simulation techniques that have been used in this regard. Manout et al. (2021) presented a transportation agent-based model to predict the rate of infection in the public transportation. They used the SIR framework with seven different transition states. They concluded that epidemic predictions are significantly sensitive toward errors in input data. Peng-yun and Hui (2020) used a system dynamics approach to simulate the spread of COVID-19 in the transportation systems. They showed that the increase in public transport proportion will accelerate the spread of COVID-19.

To the best of our knowledge, there is no more related research in the literature that used a simulation technique to model the spread of the virus in the public transportation. However, based on Currie et al. (2020) and Wang and Flessa (2020), there is a lack of studies on this problem and DES could be used to model the transportation process. Nevertheless, there are some papers in the literature that used DES or hybrid approaches to model epidemiological outbreaks generally.

Perumalla and Seal (2011) presented a discrete event simulation approach in order to model the epidemiological outbreaks. The main idea of their work is to develop a parallel computing method to overcome different challenges about population size, phenomenological process complexity, and runtime speed. They supposed that virus transmission could be due to "physical proximity" and "meetings and other co-located activities". They used a reaction function to define the infection behavior of co-located individuals. In fact, this function shows the probability of virus transmission from one entity to another.

Yaylali et al. (2016) surveyed pertussis spread by using discrete event simulation. They modeled the response of a local health department to a pertussis outbreak by using discrete event simulation combined with a stochastic branching process. The spread of the disease is simulated by a probability distribution. One of the main results of this work was the development of an approach to simulate and control the outbreak. They concluded that the number of hours per week available for contact tracing is an important factor in the outbreak.

Jalayer et al. (2020) developed a DES model composed of ABS to simulate spatiotemporal dynamics of Covid-19. Their model could be used to simulate the virus spread at any geographical scale. They used DES as a tool to model everyday activities such as food provisioning, shopping, refueling, and so on.

Haghbayan et al. (2021) developed a DES model to estimate the new cases of COVID-19 in Iran. They constructed their model based on governmental actions and people's behavior. They also defined three scenarios for governmental actions and predicted the new cases and cumulative death of implementing each scenario. They finally concluded that the best option for the government is to keep social distance and close to economic activity.

Stapelberg et al. (2021) presented a discrete-event, simulated social agent based network transmission model to estimate the spread of COVID-19 in large cities of Australia. They finally compared their results with real case incidence data for each city. They also defined multiple scenarios for physical distancing restrictions.

Kang et al. (2021) conducted a model-based simulation analysis to estimate the infection trends of the pandemic. They used DES and ABM approaches as a hybrid tool to predict the spread of the virus. They analyzed different social distancing policies and population movements. The model was applied in South Korea.

Table I. Summary of the literature

	Features of the model				*Scenario Analysis*	*Case study*	*Simulation approach*
	Social distancing	*Self-protection*	*Virus transmission between entities*	*Transportation system*			
Manout et al. (2021)	*			*	*	*	ABM
Peng-yun and Hui (2020)	*			*	*	*	SD
Perumalla and Seal (2011)	*					*	DES
Yaylali et al. (2016)	*					*	DES
Haghbayan et al. (2021)	*	*			*	*	DES
Stapelberg et al. (2021)	*	*	*		*	*	Hybrid
Kang et al. (2022)	*	*	*		*	*	Hybrid
Current research	*	*	*	*	*	*	DES

Therefore, we can conclude that there is little or no research in the literature on the applications of DES in the spread of COVID-19, especially in the public transportation system.

III. MODEL DESCRIPTION

In this section, we develop our model based on the framework of COVID-19 transmission proposed in previous studies. Up to now, available evidence indicates that the COVID-19 virus is transferred when an infected person is in close contact with another person. Virus transmission occurs mainly through two ways: direct contact (breathing, sneezing, coughing, etc.) and indirect contact (hand-mediated transfer of virus). On the other hand, the main ways to prevent transmission of the virus are social distancing and self-protection (Shiu et al., 2019). We assume in our model that passengers generally could be divided into healthy or infected passengers. Infected passengers, in turn, could be categorized into "Acute" or "Not Acute" passengers (Lotfi et al., 2020).

An infected person who has symptoms can infect healthy passengers. If healthy passengers wear a mask, the probability of infection decreases. On the other hand, if social distancing cannot be maintained, the probability of infection increases. These probabilities also depend on the compliance of healthy passengers towards COVID-19 prevention practices such as self-protection (wearing a mask) or social distancing tips.

A. Overall simulation procedure

Figure 2 shows the importance of self-protection and social distancing in a crowded area such as the metro. An infected passenger (which is highlighted by red color) could infect healthy passengers (which are indicated by white color) who are in close contact with her/him. Self-protected passengers who are seated close to the infected passenger could be infected probably. But the probability of infection for far self-protected passengers is low (Gameiro Da, 2020; Dzisi and Dei, 2020; Hu et al., 2020).

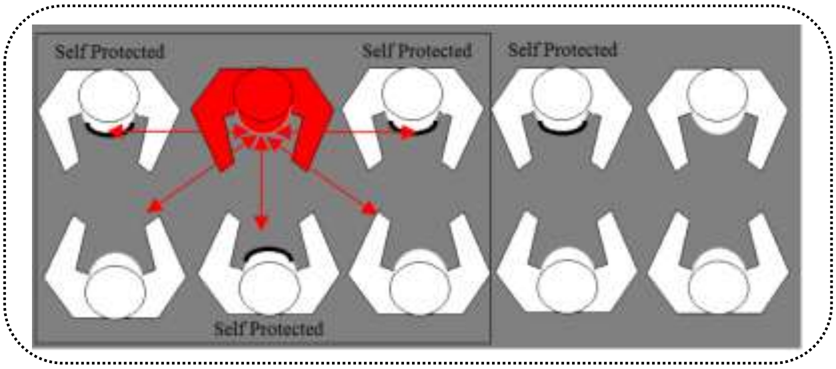

Fig 2. A schematic view of virus spread in a congested area

A distinguished characteristic of the virus spread model in the metro is the time of the trip. Obviously, if an infected passenger and healthy passengers are simultaneously present in the metro, the virus transmission could occur.

The above discussions could be summarized by a flowchart describing the procedure of simulation. The main procedure of the simulation is depicted in figure 3. Each passenger has a specific pair of origin and destination; therefore, the time of the trip is known. Whenever the trip is carried out, passengers get off the train, and therefore, virus transmission is not possible. Indeed, virus transmission could be occurred by the following procedure:

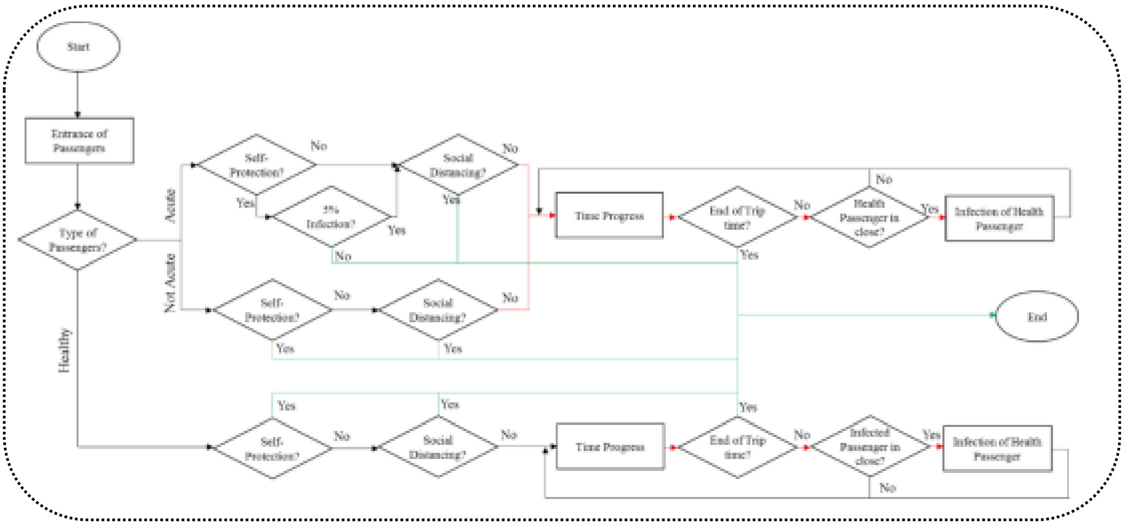

Fig 3. Simulation Procedure of the virus transmission in metro

Passengers with acute conditions can easily spread the virus in crowded areas. Even N95 masks could not filter out all viruses. Thus, there is a 5 percent probability that this passenger infects healthy passengers who are close to her/him. It also depends on the self-protection of healthy passengers. We assumed that the probability of virus transmission from a passenger with the not acute condition to healthy passengers is negligible when they comply with self-protection requirements and social distancing tips (Lotfi et al., 2020).

In order to implement the simulation procedure, we used Arena Software version 14. Arena is a powerful tool to simulate stochastic models. It uses the SIMAN language to develop simulation models. In this software, the user can develop a model by inserting graphical modules that represent the logic of simulation. Modules are connected by using lines in order to specify the flow of entities. Statistical data could be used as inputs to run a model, and a wide range of outputs could be obtained.

Based on the simulation procedure explained in figure 3, an overview of the simulation model is depicted in figure 4.

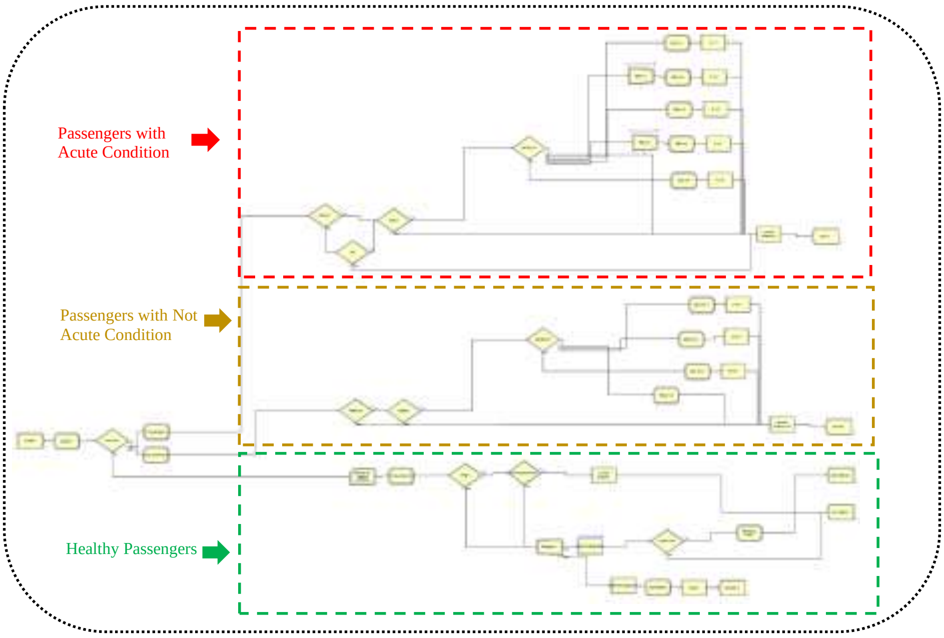

Fig 4. An overview of the proposed simulation model

Followings, we discuss more details about each section of the proposed model.

The behavior of passengers (self-protection and social distancing) is important in the transmission of the virus. If they use a proper mask and comply with social distancing, the probability of virus transmission is negligible. Otherwise, they could be subjected to the infection.

Based on the reports[1] published by the Ministry of Health and Medical Education, about 2.5 percent of Tehran's population has been infected by the coronavirus. About 17 percent of them have acute conditions (Pourmalek et al., 2021; Nikpouraghdam et al., 2020). Therefore 0.425 percent of all metro entries in Tehran are infected and have acute conditions and 2.075 percent of them are infected but have no acute conditions.

B. Passengers with acute conditions

We assumed that 0.425 percent of all passengers of the Tehran metro have acute conditions. These passengers if they do not comply with self-protection and social distancing tips may infect healthy passengers who are in contact with them. Based on Azimi et al. (2020), we assumed that R0 (the number of cases directly caused by an infected individual) in Iran is estimated between 1 and 3. On the other hand, based on Agrawal and Bhardwaj (2021), the probability of transmission of disease in a closed space depends on the health condition of the infector and the distance between passengers. According to the data gathered by Tehran Urban & Suburban Railway Operation Company we assumed the probability of infection as tables 2 and 3.

Table II. Number of healthy passengers infected by a passenger with acute condition

Probability	0.05	0.25	0.35	0.2	0.1	0.05
Number of Healthy Passenger who infected by a passenger with acute condition	0	1	1.5	2	2.5	3

The simulation procedure of the acute passengers is depicted in figure 5.

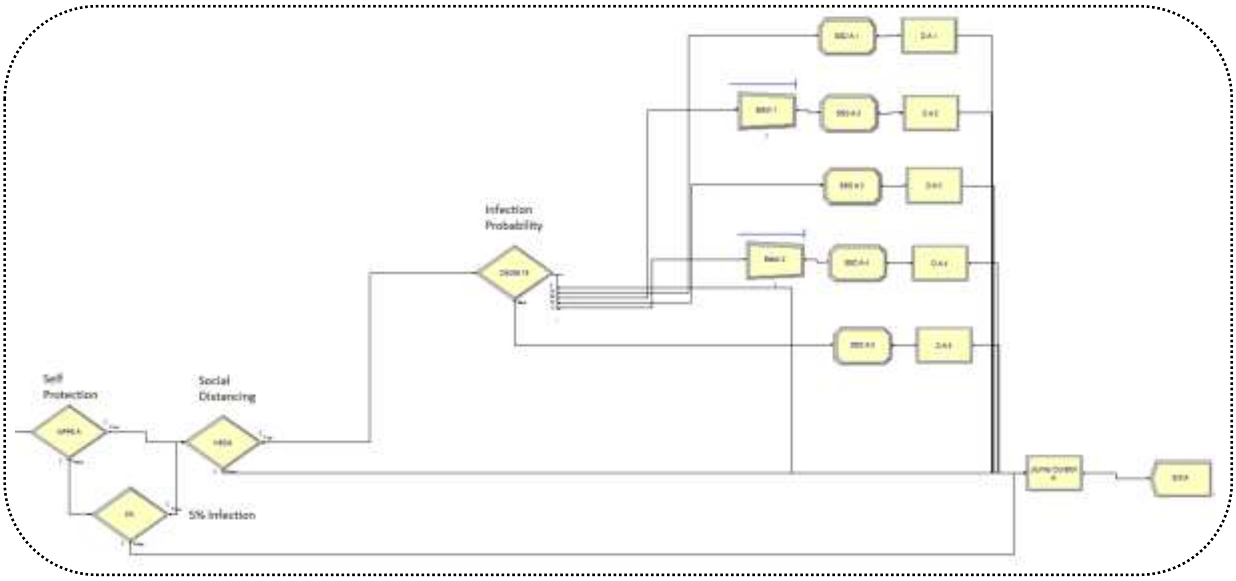

Fig 5. Simulation procedure of passengers with acute conditions

In this model, we used a "signal" module to send a signal command (Infection Signal) to healthy passengers that are waiting on the train to reach their destinations (healthy passengers whose their trip time is not ended yet). The process of

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[1] www.health.sbmu.ac.ir

healthy passengers' trip will be described in the following sections.

C. Passengers with Not acute conditions

We assumed that 2.075 percent of all entries of Tehran metro are infected by coronavirus but have no acute condition. These passengers have no symptoms but could infect other healthy passengers. We assumed that the number of healthy passengers infected by a passenger with no acute condition follows as the probability distribution shown in table 3.

Table III. Number of healthy passengers who infected by a passenger with Not acute condition

Probability	0.3	0.55	0.1	0.05
Number of Healthy Passenger infected by a passenger with Not acute condition	0	1	2	3

The simulation procedure of the not acute passengers is depicted in figure 6.

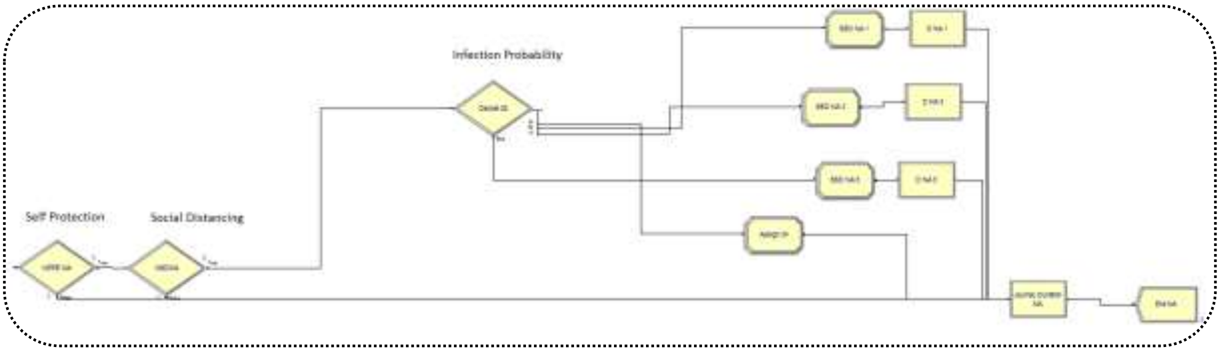

Fig 6. Simulation procedure of passengers with not acute conditions

The overall procedure is same as acute passengers, but the probability of virus transmission from these passengers is significantly lower than the acute passengers.

D. Healthy Passengers

We assume that 97.5 percent of passengers are not infected by the coronavirus and are healthy. They enter the train and if complying with self-protection and social distancing, they are not infected during the trip. Those who are not complying with self-protection and social distancing probably are infected if there exist infected passengers nearby. These entities are waiting in a holding module. If the time of the trip is ended, the entity is released from the holding module. If during the trip, an infected passenger with no mask comes close to her/him (do not comply with social distancing), the infection signal is activated and she/he is getting infected. This procedure is depicted in figure 7.

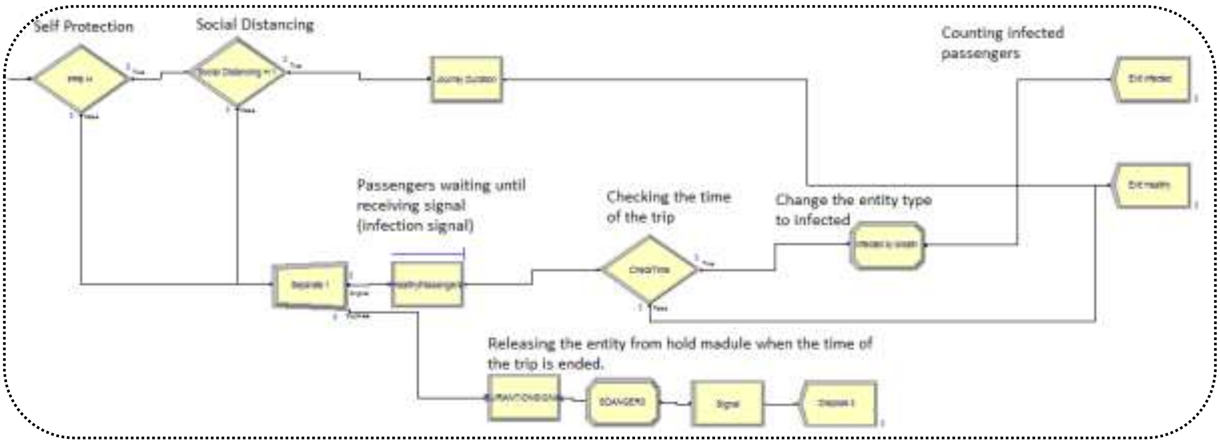

Fig 7. Simulation procedure of healthy passengers

The number of infected healthy passengers depends on the percent of passengers which comply with self-protection and social distancing.

In the next section, we will present different scenarios to analyze the model in different situations.

IV. RESULTS

Tehran metro is one of the largest transportation systems in the Middle East. During peak hours, stations and trains are crowded. Many people use the metro to commute to and from work. Tehran metro operates daily for 14 hours. Before the pandemic, it carries more than 2 million passengers a day, with 7 active lines[2]. During the pandemic, the number of passengers was almost halved.

The time period to run the model in this paper is 31 days. In order to simulate the peak days, we assumed that the number of passengers is 500000 on the first day of simulation and increases gradually to reach 2 million passengers a day on the last day of simulation.

Sensitivity Analysis

Sensitivity analysis is usually used to assess the sensitivity of outputs to changes in inputs. In this approach, the effects of changes in one parameter on the outputs of the model will be assessed. The important parameters of this model are the percentage of compliance with self-protection rules, and the percentage of compliance with social distancing. Based on the real data gathered by Tehran urban & suburban railway operation company, the percentage of compliance with self protection rules could be assumed at 75% (for healthy and infected passengers) and the average percentage of compliance with social distancing could be assumed at 50% (for healthy and infected passengers). Table 4 shows the sensitivity analysis of the model with regard to changing these inputs.

Outputs of the model are the Total Number of Healthy Passengers Infected during the Trip (TNHPIT) and the Ratio of Healthy Passengers getting Infected during the Trip to all Healthy Passengers (RHPITHP).

Table IV. Results of the sensitivity analysis

	Percentage of the chnage	*TNHPIT*	*RHPITHP*
The percentage of compliance with self protection rules	+20%	160632	0.0070
	+10%	165600	0.0072
	+5%	170721	0.0075
	Base value	176002	0.0077
	-5%	177762	0.0078
	-10%	179539	0.0079
	-20%	181335	0.0079
The percentage of compliance with social distancing	+20%	150899	0.0066
	+10%	158841	0.0069
	+5%	167201	0.0073
	Base value	176002	0.0077
	-5%	184802	0.0081
	-10%	194042	0.0085
	-20%	203744	0.0089

Results of table 4 show that by ±20% change in the compliance of passengers with self protection rules, RHPITHP

[2] www.metro.tehran.ir

changes between 0.0070 and 0.0079. On the other hand, by a ±20% change in the compliance of passengers with social distancing, RHPITHP changes between 0.0066 and 0.0089.

Scenario Analysis

We defined seven scenarios regarding the compliance of passengers with self-protection and social distancing tips. These scenarios are defined in table 5.

Table V. Percentage of compliance with self-protection and social distancing tips

Scenarios	*Passengers*	*Infected (Acute Conditions)*	*Infected (Without Acute Condition)*	*Healthy*
1	Self-Protection	100%	100%	100%
	Social Distancing	95%	95%	95%
2	Self-Protection	100%	100%	50%
	Social Distancing	95%	95%	50%
3	Self-Protection	50%	50%	100%
	Social Distancing	50%	50%	95%
4	Self-Protection	75%	75%	75%
	Social Distancing	75%	75%	75%
5	Self-Protection	75%	75%	50%
	Social Distancing	75%	75%	50%
6	Self-Protection	50%	50%	75%
	Social Distancing	50%	50%	75%
7	Self-Protection	50%	50%	50%
	Social Distancing	50%	50%	50%

It is worthwhile to note that in crowded areas such as metro wagons on peak days, compliance with social distancing is almost not possible. Therefore, the optimistic scenario for complying with social distancing is a maximum of 95%, but the compliance with self-protection tips depends on the passenger.

In scenario 1, compliance with social distancing and self-protection tips is at the maximum level. In scenario 7, these are at the minimum level. In scenarios 2 and 5, infected passengers are more compliant with the health tips than the healthy passengers. In scenarios 3 and 6, healthy passengers are more compliant with the health tips than infected passengers. In scenario 4, the percentage of compliance with self-protection and social distancing tips is equal to a fixed value and indeed, it is an intermediate scenario.

In this paper, a simulation-based estimation approach is adopted to estimate some criteria through Monte Carlo simulation. The basic idea is that the variables of the model are calculated by repeatedly applying the model to a sampling of the stochastic parameters and calculating the corresponding values of the criteria. Running the model with each set of stochastic parameters is called replication. We execute the model with 10 and 20 replications. Results are presented in table 6.

Results show that based on the assumed parameters, in the optimistic scenario (scenario 1), at least 0.5 percent and a maximum of 0.7 percent of the healthy passengers are getting infected during the trip. Also, in the pessimistic scenario (scenario 7), at least 1.28 percent and a maximum of1.64 percent of the healthy passengers are getting infected during the trip. The comparison of results in scenarios 2 and 3, and also scenarios 5 and 6 show that compliance of infected passengers with the health tips is almost twice important as the compliance of healthy passengers.

Table VI. Results of the simulation model in each scenario based on 10 replications

Number of	Run Time (s)		Average				Minimum				Maximum			
			TNHP	TNIP	TNHPIT	RHPITHP	TNHP	TNIP	TNHPIT	RHPITHP	TNHP	TNIP	TNHPIT	RHPITHP
10	12	Scenario 1	22852389	585217	13130	0.0006	22623865	555956	11817	0.0005	23080913	596921	15756	0.0007
		Scenario 2	22863321	585739	34294	0.0015	22406055	556452	30865	0.0014	23320587	597454	41839	0.0018
		Scenario 3	22852495	585516	63986	0.0028	22623970	562095	58867	0.0026	23538070	603081	78703	0.0033
		Scenario 4	22849437	585014	98252	0.0043	22163954	567464	91374	0.0041	23077931	602564	121832	0.0053
		Scenario 5	22852790	585209	127975	0.0056	22624262	567653	120297	0.0053	23309846	602765	158689	0.0068
		Scenario 6	22860042	585991	224028	0.0098	22402841	568411	210586	0.0094	23545843	609431	280035	0.0119
		Scenario 7	22850029	585855	305779	0.0134	22393028	574138	287432	0.0128	23307030	615148	382224	0.0164
20	25	Scenario 1	22852411	585223	13135	0.0006	22623854	555932	11804	0.0005	23080924	596933	15779	0.0007
		Scenario 2	22863322	585765	34315	0.0015	22406036	556429	30850	0.0014	23320615	597481	41843	0.0018
		Scenario 3	22852495	585525	64004	0.0028	22623965	562077	58851	0.0026	23538077	603099	78713	0.0033
		Scenario 4	22849438	585021	98258	0.0043	22163927	567452	91372	0.0041	23077939	602590	121839	0.0053
		Scenario 5	22852797	585218	127985	0.0056	22624241	567635	120281	0.0053	23309856	602787	158706	0.0068
		Scenario 6	22860043	586002	224056	0.0098	22402817	568381	210559	0.0094	23545848	609438	280046	0.0119
		Scenario 7	22850031	585868	305794	0.0134	22393017	574125	287411	0.0128	23307038	615151	382254	0.0164

TNHP: Total Number of Healthy Passengers
TNIP: Total Number of Infected Passengers
TNHPIT: Total Number of Healthy Passengers Infected during the Trip
RHPITHP: Ratio of Healthy Passengers getting Infected during the Trip to all Healthy Passengers

Another important insight that could be obtained from the proposed model is the impact of self-protection on the virus spread in the metro whenever the compliance of all passengers with social distancing is at the maximum level and vice versa. Figure 8 depicts the results of the average RHPITHP obtained from the simulation model.

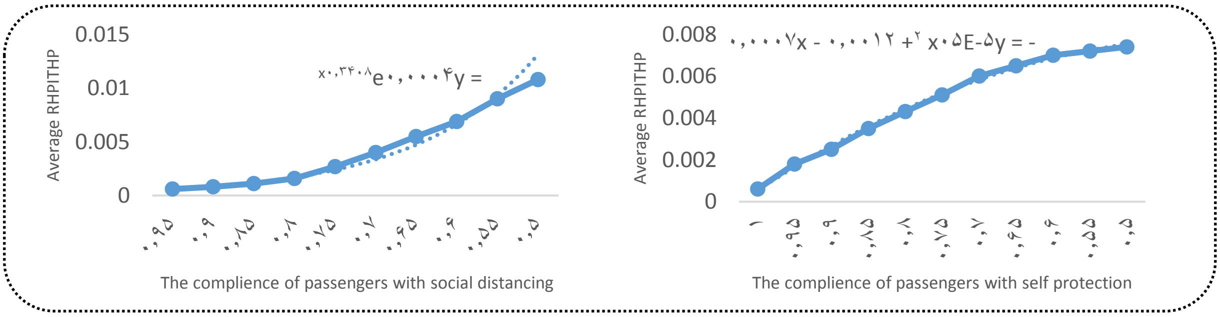

Fig 8. The average value of RHPITHP in the case that the compliance of all passengers with self-protection is 100% (Left); the average value of RHPITHP in the case that the compliance of all passengers with social distancing is 95% (Right).

Based on the results of figure 8, whenever all passengers fully comply with self-protection tips, the Ratio of Healthy Passengers getting Infected during the Trip to all Healthy Passengers (RHPITHP) in the worst case of compliance with social distancing reaches 1.08%. Also, whenever all passengers fully comply with social distancing, the worst level of compliance with self-protection tips reaches 0.74%. Therefore, we can conclude that social distancing almost has an exponential effect on the RHPITHP.

V. VALIDITY OF THE PROPOSED MODEL

According to Raunak and Olsen (2014), the most commonly used techniques for validating simulation models are divided into two categories: Input data (id) and observable emergent information (oei). Validation of "id" could be done through face validation using subject matter experts and goodness-of-fit tests. Validation of "oei" could be done through face validation through subject matter expert review and extreme condition test.

Face validation of input data has been done by reviewing the input data assumed in this paper by the experts of Tehran Metro and also the experts of the ministry of health and medical education. In addition, by using the input analyzer tool of Arena software, the chi-squaretest and KS test have been applied to the inputs. Based on the best fited distribution outputs, we defined the input distributions such as time between arrivals of passengers and journey durations.

Face validation of output data has been done through reviewing the outputs by the experts of Tehran Metro and also the experts of the ministry of health and medical education. By subjecting the model to extreme conditions, we can verify whether the model provides reasonable outputs. Extreme conditions of the model are 1-100% compliance of the passengers with the Self Protection (SP) and Social Distancing (SD) rules, and 2- 0% compliance of the passengers with the Self Protection (SP) and Social Distancing (SD) rules. Results of the simulation showed that 100% compliance with SP and SD rules decreases RHPITHP to zero and 0% compliance with SP and SD rules increases RHPITHP to the maximum level (i.e. 1).

VI. CONCLUSION

In complex phenomena such as outbreaks, simulation is the most effective method for proactive or reactive analysis (Perumalla and Seal, 2011). In this paper, we examined the effect of two important public and private practices to prevent the transmission of coronavirus: Self-protection (e.g. wearing a mask) and social distancing. These are more important in crowded areas. Many people daily use public transportation such as the metro, and especially at peak hours, passengers are in close contact with each other in a confined space. The risk of respiratory virus transmission in a crowded area is extremely high. In order to study the impact of these practices on virus transmission, we developed a discrete event simulation model in which passengers enter the system, and depending on the compliance level of passengers with self-protection tips and social distancing, virus transmission could occur. Different scenarios have been developed regarding the compliance of passengers with self-protection and social distancing tips. Results showed that in the optimistic scenario, at least 0.5 percent and a maximum of 0.7 percent of the healthy passengers are getting infected during the trip. Also, in the pessimistic scenario, at least 1.28 percent and a maximum of 1.64 percent of the healthy passengers are getting infected during the trip. Also, results of the scenario analysis showed that the compliance of infected passengers with the health tips is almost twice important as the compliance of healthy passengers. The other conclusion that has been resulted from the scenario analysis is that whenever all passengers fully comply with self-protection tips, Ratio of Healthy Passengers getting Infected during the Trip to all Healthy Passengers (RHPITHP) in the worst case of compliance with social distancing reaches 1.08%. Also, whenever all passengers fully comply with social distancing, in the worst level of compliance with self-protection tips, it reaches to 0.74%. In addition, the results of the simulation showed that the compliance of infected passengers with the health tips is almost twice important as the healthy passengers. In addition, social distancing almost has an exponential effect on the Ratio of Healthy Passengers getting Infected during the trip to all Healthy Passengers.

Future studies could be concentrated on the impact of air conditioning on virus transmission in public transportation, the impact of train schedules on the number of passengers who are getting infected during the trip, and the financial analysis of implementing prevention strategies such as exemplary physical distancing, lockdown or decreasing working hour.

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