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Evaluation and improvement of the resilience of a transportation system against epidemic diseases: A system dynamics approach

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ABSTRACT

The influential role of health protocols in preventing the spread of the COVID-19 disease has led governments to seek effective methods for implementing these protocols in society. Considering the importance of public transportation system in spread of viruses, this paper introduces and analyzes some methods of inspecting urban public transportation companies using a system dynamics approach. First, the base model, which represents the status of a public transportation terminal, was created and validated using a system dynamics simulation approach. Then the impact of two penalty policies, including fixed penalty policy (FPP) and variable penalty policy (VPP) on the violations within the terminal was investigated. The simulation results show that the variable penalty policy significantly reduces the violations of passenger terminal drivers. Next, the extended model was developed which considered several terminals. Finally, by presenting two policies of fixed inspector assignment (FIA) and variable inspector assignment (VIA), the effect of four scenarios of combining inspection and penalties was investigated. The simulation results showed that combining the variable penalty and variable inspector assignment policies could significantly reduce terminal violations. Also, the implementation of this policy does not require an additional inspector. The results can help city managers to adopt appropriate inspection policies.

1. Introduction

Following the COVID-19 pandemic, irreparable damage has occurred to the world. Most industries, including tourism and welfare services, transportation services, and other urban services, have been affected by this disaster (Hobbs, 2020; Ntounis et al., 2022). According to reports, public transportation in some cities has decreased by 90% (Gkiotsalitis and Cats, 2021b). Governments seek disaster relief and improve resilience to the disease in a variety of ways. Urban resilience against epidemics has been studied in several studies (Blay-Palmer et al., 2021; Kaye-Kauderer et al., 2021). Effective action in urban resilience is the provision of health protocols for various industries, and implementation of these protocols will prevent the spread of the disease in different areas (Giallonardo et al., 2020). One of the essential urban services that play a crucial role in preventing the outbreak of Covid-19 disease is the urban public transportation fleet (Gkiotsalitis and Cats, 2021b). Observing the maximum number of passengers in each vehicle, drivers and passengers using masks, disinfecting the vehicle after each trip, and spacing between passenger seats are among the rules in the form of health protocols, that transportation companies and public terminals are required to implement (Tirachini and Cats, 2020).

A critical issue after the approval of protocols is monitoring and review for their proper implementation. Experience has shown that organizations and companies fail to comply with the law without supervision and inspection (Nourinejad et al., 2020; Rass et al., 2020). However, the limited resources to inspect and penalty violators is a challenge facing inspection organizations. Choosing the right inspection policy and strategy in many cases can effectively reduce the rate of violations (Rass et al., 2020; You et al., 2020). As a result, one of the problems that researchers seek to solve is to review and determine better inspection policies in different situations using various approaches (Morales et al., 2020; Tsebelis, 1990).

The interactions among inspectors, public transportation system staff and passengers are uncertain. This makes the determination of most suitable inspection policies complex. On the other hand, necessity of addressing inspection policies over time makes the problem at hand dynamic. The complexity of these problems has led some researchers to use the system dynamics approach in simulation (Nabi, El-adaway, &
Dagli, 2020; Wang et al., 2020). It is essential to study the role of urban public transportation companies’ inspections in coping with epidemic disasters. This study explicitly addresses government inspections of urban public transportation companies to implement one of the essential health protocols (number of vehicle passengers) using the systems dynamics approach. In this regard, the research questions considered in this study are:

A) What factors are effective in decreasing the number of violations of public transportation companies?

B) How to model these factors using the system dynamics approach?

C) How to compare the proposed inspection policies and which of them is more effective?

This study for the first time examines the relationship between government inspections, urban public transportation companies, and the number of violations committed in an epidemic disaster using a system dynamics approach and seeks to provide efficient and effective policies to inspect urban public transportation companies during an epidemic. In this regard, passenger entry rates to the terminal, the risk, and the behavior of transportation companies and drivers have been considered. Also, the impact of various inspection policies on the number of illegal passengers and the number of offending vehicles, in the long run, is examined for the first time.

The rest of this paper is organized as follows. In Section 2, a literature review is described. In the third section, the definition of the problem is given and the structure of the base model is explained. In section four, inspection policies are defined and modeled, and by using simulation, the results of each policy are presented. The fifth section provides an analysis and comparison between policies and presents managerial perspectives. Finally, the sixth section summarizes the content and conclusions and offers suggestions for future research.

2. Literature review

The present study examines the issue of inspection of public passenger transportation companies to observe the social distance in vehicles, which is one of the criteria in the health protocols, using the system dynamics approach. Thus, it is necessary to review the literature on “Public transportation system and epidemic disaster” and “System dynamics, transportation and inspection.”

2.1. Public transportation system and epidemic disaster

With the onset of Covid-19 disease, many studies have examined the various dimensions of this catastrophe. Part of these researches can be found in the relationship between Covid-19 and public transportation system services. A group of researchers investigated the effects of COVID19 disaster on public transportation services. Using a questionnaire approach (Mogaji, 2020), examined the impact of Covid-19 on Lagos public transportation services in Nigeria. His research shows that Covid-19 has a significant effect on public transportation services and has disrupted the people’s economic, social, and religious activities due to its disruption. Downey et al. (2022) investigated the impact of Covid on the future of public transport in Scotland using a questionnaire. According to the results, some factors significantly affected the use of public transportation, one of which is the perceived risk of COVID-19 infection. More than 60% of those who intended to use less public transportation considered the possibility of contracting Covid-19 from other passengers as an influential factor in this decision (Jenelius and Cebeauer, 2020). The effects of covid on the daily use of public transportation in Sweden. Based on ticket sales data and passenger counts, they found a sharp drop in the use of public transport due to the spread of COVID-19 in the three largest Swedish cities. Bucky (2020) studies confirm an 80% decrease in the use of public transportation during the outbreak of covid in Budapest, Hungary. Similar studies have examined the impact of this disaster on transportation in Colombia, Canada, China, Greece, India and other countries (Arelalma et al., 2020; Cai et al., 2016; Tian et al., 2021).

There have also been several studies on transportation system measures to prevent the spread of Covid-19. Dzisi and Dei (2020) examined the observance of social distancing and masks in Ghana’s public transportation during the epidemic using observations. The results of 850 samples observed by the roadside observer indicated that social distancing was more observed than wearing a mask in public transportation. They also pointed out the spread of disease in public transport and suggested fines to enforce the rules. Shen et al. (2020) provided an overview of measures taken in China to manage public transportation in the field of Covid-19, from substance disinfection to information campaigns. Referring to medical research on viruses remaining on the surfaces and transmission of microorganisms, Musselwhite et al. (2020) considered the cleaning and internal hygiene of public transportation vehicles to be among the most critical activities of the health protocol. Due to the social distancing provided by the World Health Organization, studies have addressed a reduction in the capacity of vehicles when transporting passengers (Gkiotsalitis and Cats, 2021a), redesigned transportation services to reduce costs and reduce passenger capacity by presenting a quadratic mixed planning model. In continuation of the previous research, the present study also refers to reducing public transportation capacity during a disease outbreak.

2.2. System dynamics, transportation and inspection

System dynamics has been introduced as a new way to assess and control corporate performances (Forrester, 1997). The main idea in system dynamics is that every system consists of components interacting with each other. Feedback loops record interactions between system components and the overall pattern of system behavior over time (Zarghami et al., 2018). The nonlinear relationships between the components of economic and social systems and their complexity have made it very difficult to analyze their behavior. System dynamics theory uses simulation to understand complex systems’ dynamic behavior as they change over time. System dynamics is an efficient approach for analyzing systems in various fields such as management (Xiao et al., 2020), economics (Cosenza et al., 2020), epidemic (Currie et al., 2020), etc.

Also, the dynamic system approach has been used by researchers in various fields and issues of transportation such as airports and airlines (Suryani et al., 2012), road transportation (Gupta et al., 2019), highway maintenance (Fallah-Fini, Rahmandad, Triantis and de la Garza, 2010), urban transport system (Fontoura et al., 2019), sustainable urban transportation (Sayyadi and Awasthi, 2020), and other cases. Specifically in the field of public transport (Ercan et al., 2016), explored the impact of public use of public transport on CO2 emissions and energy consumption, using a dynamic system approach. The specificity of the system dynamics approach allowed them to consider many variables in their model, such as labor force population, the number of individual trips, mode of transportation preferences, fuel/energy consumption, and CO2 emission effects. Bajracharya (2016) studied the individuals’ mode choice behavior in the context of a city and the issue of the propensity for public transportation versus personal vehicle. The proposed system dynamics model included transportation aspects like travel time, travel cost, and station accessibility.

Ghosh et al. (1998) stated the first application of the system dynamics in the inspection process to control the hazards in the mines. First, they described hazard as an unsafe situation in a mine. Then using the system dynamics model, they identified systematic behavior in the mines and factors affecting safety against hazards and examined the effect of policy variables such as safety rules, inspection, and direct risk elimination. They concluded that management actions like inspections significantly improve the mining safety system. The application of system dynamics in mine safety was raised again by (Liu et al., 2015). The
focus of this study was specifically on the coal mines and inspection system. By presenting an evolutionary game on coal mines, they examined the interactions between the issue’s stakeholders, including the State mines safety inspection agency, the local mines safety authority, and coal companies. Using simulation based on system dynamics approach, these researchers presented how to balance stakeholder decisions. After this study, other researchers used the evolutionary game theory approach and the system dynamics for mine safety and did similar work (Liu et al., 2019; Ma et al., 2020; Yu et al., 2019; Zhao et al., 2017). Duan et al. (2016) studied the environmental pollution control using evolutionary game theory and system dynamics. By examining two system dynamics models based on static and dynamic penalty policies, they discussed the interactions between government, industry, and the interests of society as a whole. In a dynamic penalty policy, the proportion of government inspections of industries increases as pollution in society increases. They showed that the implementation of hybrid policies has a more significant impact on improving the overall interests of society. In another study (Cai et al., 2016), used evolutionary game theory and system dynamics to examine government legislation to address environmental pollution problems and inspect and monitor its implementation. These researchers, like other studies, defined the decision of companies to enforce or violate laws, the decision of inspection and non-inspection for the government, and concluded that the penalty coefficient has a significant impact on the legitimacy of companies. Azmi and Tokai (2017) estimated the number of used cars and electric vehicles in 2040 for Malaysia using the system dynamics approach. They examined the impact of different inspection strategies for collecting and replacing used vehicles, tax policies, and related laws through simulation. The results of their study showed that with the correct implementation of tax policies, inspection policies, and pollution standards regulations, the number of electric vehicles can increase by up to 70%. Zhu et al. (2020) examined food waste management using the evolutionary game and the system dynamics approach. Referring to the conflict of interest between the government, restaurants, and garbage collection companies, they presented a system dynamics approach in which the government legislates and enforces inspections and penalties to prevent illegal behavior. Reviewing the results, they considered the existence of inspection and penalty plans necessary to reduce food waste and effective waste management.

3. Problem structure and formulation

3.1. Problem definition and assumptions

Due to the problem of epidemic diseases and the increasing number of patients, health protocols for the continuation of public transportation terminals activities have been defined as follows:

A) The driver and passengers must wear a mask.
B) Passengers at terminals and stations must observe the social distance.
C) Public transportation must be disinfected several times during the day.
D) In public transportation, social distance must be observed (the number of passengers must be determined within the criteria).

Although the first three clauses of these protocols do not cost much for drivers and passengers of public transport, not taking the passenger with an empty seat in a public vehicle will have a financial cost for drivers, which results in the driver’s tendency to disobey and violate. Drivers of this type of equipment govern this law. Various reports indicate that many drivers of public passenger terminals do not comply with the law. However, if the policy of inspecting public passenger transportation is not appropriately implemented, the results of the enacted laws will be nothing but an outbreak of the disease. This paper uses a simulation model for assessment and analysis of this problem. The assumptions considered in this simulation model are as follows:

1 The passenger’s incoming rate to the terminal follows the Poisson distribution with a variable mean rate. This rate per specific hour of day is proportional to the volume of the public travel demand in the city in that hour. The hourly distribution of demand is the same on different days. In this study, the hourly demand information of public transportation trips in Isfahan (a city in the center of Iran) has been used to determine the average Poisson rate at different day hours.
2 The headway of vehicles (here bus) from the terminal is fixed. (Here 15 min)
3 Public transport vehicles all have the same specific passenger-carrying capacity. (25 passengers here)
4 The maximum number of passengers in each vehicle is specified according to health protocols. (15 passengers here)
5 The daily working hours of the terminal are specified. (Here from 8 a. m. to 8 p.m. for 12 h)
6 For the remaining passengers during the hours outside the working hours of the terminal, transportation services are not provided.
7 The average available inspection capacity is a certain amount. (Here 50 inspections per month, which is equivalent to 0.12 per hour)

Based on these assumptions, we now express the problem. During the daily working hours of the terminal, passengers enter the terminal randomly and are interested in getting on the bus as soon as possible and going to their destination. Every 15 min, a bus starts its trip from the terminal. During this time, one of the following four situations can occur. The first situation is when the number of passengers present in the terminal is less than 15. In this circumstance, the bus driver will pick up all the passengers and leave the station without additional passengers, and no passengers will be left behind. The second situation is when the number of passengers present at the terminal exceeds 15, but the driver decides to abide by the law. In this case, the driver will pick up 15 passengers and leave the terminal, and passengers who have not been able to board the bus will have to wait for the next bus. The third situation is when the number of passengers present at the terminal is between 15 and 25, and the driver decides to break the law. In this case, the driver will pick up all the passengers and leave the terminal, and there will be no passengers left for the next bus. Finally, the latest situation is when the number of passengers present at the terminal exceeds 25, and the driver decides to break the law. In this case, the driver will pick up 25 passengers and leave the terminal, and passengers who have not been able to board the bus will have to wait for the next bus.

With the initial definition of the problem and the assumptions associated with it, modeling is performed for situations that a passenger transportation terminal exists. This model is called the base model, and its purpose is to identify the behavioral pattern of the system and its main components.

3.2. Base model structure: current situation

In the modeling stage, the causal loop diagram is first presented to create the base model. In this diagram based on the definition of the problem and the dynamic hypotheses presented in the previous section, the problem variables and the causal relationships between them are defined. This model assumes that there is only one terminal. Drivers do not consider themselves bound by law enforcement. Then a flow diagram is drawn, and in the flow diagram state and rate variables are specified, and the relationships between the variables are shown more precisely than the causal loop diagram. The causal loop diagram can be seen in Diagram 1 and the related flow diagram in Diagram 2. Also, to better understand and develop the base model, the flow model’s equations have been placed in Appendix A.
In this study, all the flow diagrams symbols used in each diagram are defined to the right of the diagram. It is necessary to explain the symbols used in the Diagram 2. In the description of the base models’ flow diagram, it should first be said that the headway interval of buses is 15 min, and as a result, each working day includes 14 working hours, that means 57 buses a day exit from the terminal. The number of terminal passengers (TP) varies under the influence of two factors. Passenger arrival rate (PAR) to the terminal and passenger departure rate (PDR) by bus. Due to the assumption that at the end of the terminal working hours, the remaining passengers will not be served, these passengers will leave the terminal at the end of the working day without receiving services. End of day discharge rate (EDR) indicates the discharge flow of passengers at the end of the working day. Bus passengers (BP) is determined by the passenger entry rate (equivalent to the passenger departure rate by bus). Bus passengers exit rate (BPER) is the rate of unloading passengers at the destination. As mentioned, the number of authorized passengers on each bus according to health protocols is equal to 15 people. If the number of passengers on a bus exceeds this number, it will be added to the daily number of violating buses (DNVB), and the number of additional passengers on that bus will be added to the daily number of illegal passengers (DNIP). At the beginning of each day, in order to count the DNVB and DNIP, the values of these variables must be set to zero. Bus violation counter reset (BVCR) and additional passengers counter reset (APCR) are designed such that they take only at the beginning of each day, and their value at the beginning of the day is equal to the daily number of violating buses (DNVB) and the daily number of illegal passengers (DNIP), respectively. At other times of the day, the value of these variables is zero. Therefore, the bus violation counter reset (BVCR) resets the daily number of violating buses (DNVB) to zero at the beginning of the day, and the additional passengers counter reset (APCR) resets the daily number of illegal passengers (DNIP) to zero at the beginning of each day.

3.3. No-inspection policy (NIP): simulation results

The first policy that can be considered is the policy of no-inspection of terminal company (NIP). By implementing this policy, the Diagram 1 does not change. Due to the evaluation of (NIP) results, the simulation was performed for 25 days. Since the degree of risk of drivers is related to their previous information or status and fines, it is not correct to consider the model behavior in the early stages. Therefore, by testing the model and evaluating the results, it was determined that the model results have reached a stable state from the fifth day onwards and are valid after that. The first five days were set to eliminate the disturbances at the beginning of the simulation. Simulations were performed for two cases. In the first case passengers entering the terminal with a Poisson distribution with an average of 750 people per day, and in the second case passengers entering the terminal with a Poisson distribution with an average of 1500 people per day.

Apart from the passenger entry rate to the terminal, the rest of the simulation conditions are the same for the two simulated cases. In this way, it is possible to see the effect of changing the passenger entry rate component of the terminal on daily violations. Fig. 2 shows the daily number of violating buses for two cases, and the daily number of illegal passengers in those cases between the fifth and twenty-fifth day.

As shown in Fig. 2 the rate of passenger arrivals at the terminal has a significant impact on the number of daily violations at the terminals and the number of illegal passengers handled by the terminals. Increasing the number of passengers, the number of violations raises the possibility of infection and the number of patients. As a result, the need to adopt policies for the inspection of terminals is fully felt. In system dynamics models, negative feedback loops often make the system resistant to changes after policy adoption. Negative feedback loops may even lead to the aggravation of the problem in the system in the long run. As a result, by performing simulation after policy making, the results can be observed in the long term, and the resistance or change of abnormal behavior can be checked. After presenting each policy, this study examines the result of its implementation with long-term simulation. In the following, by proposing several inspection policies, the results of each simulation mode are reviewed.

4. Inspection and penalty policies and their effects

4.1. Fixed penalty policy (FPP)

In this type of inspection policy, the inspector enters the terminal at a random time of the day and inspects the bus that the passenger is riding at the moment, and he penalties the driver with fixed amount if he observes a violation, ends his inspection and leaves the terminal. The causal loop diagram of this inspection policy can be seen in Diagram 3.

As shown in Diagram 3, in addition to the passenger entry rate to the terminal, two other factors that affect the number of bus passengers are “terminal inspection rate” and “bus driver risk behavior”. The inspection rate has a similar effect on compliance with the law on drivers. If the inspector is openly present at the terminal, the drivers inside the terminal will be affected by the inspector’s presence and will decide to enforce the law. As a result, drivers’ adherence to the law will increase as the terminal inspection rate increases.

Thus, the drivers’ adherence to the law decreases over time after the most recent inspection, and drivers return to their previous process of not following the law. The rate of forgetfulness and declining regularity depends on the risk behavior of terminal drivers, which is expressed here by the term driver risk behavior. The higher the risk degree of the terminal drivers, the sooner the effect of the inspection disappears and the sooner the terminal drivers return to the violation process. Meanwhile, the value of penalties plays an essential role in the driver’s risk behavior. The higher the penalty, the later the driver forgets and the more risk-averse he becomes. The effect of drivers’ behavior on law enforcement has already been studied and confirmed in some studies (Ge et al., 2014; Sheikholeslami et al., 2021).

Explanations of the impact of terminal inspection rates and risk-taking degree on compliance with the rule are given in Diagram 4. In
this diagram, the subsystem enclosed in a square, shown as a dashed line, considers the two factors of inspection rate (INSR) and driver risk degree (RISKD) as input and the effect of these two factors on the regularity of the terminal drivers over time as output. It should be noted that the (RISKD) numerical value for drivers in the model is a number within the range of 0 and 1. For the highest risky drivers, RISKD is equal to 1, and for the lowest risky drivers, this variable is equal to 0.

Fig. 3 is drawn for two drivers with different risk degrees to understand the concept of risk-taking. The low enforcement rate can be interpreted as the probability of complying with the rules. In Fig. 3, a value of 1 at a specific time means that the inspector is inspecting the terminal at that time, and the driver will not pick up any extra passengers for fear of being fined. It means that the driver’s probability of adhering to the law equals 1. However, as time passes since the last inspection, the drivers gradually forget the inspector’s presence and tend to pick up the extra passenger, and the low enforcement coefficient decreases. However, the driver’s degree of risk-taking determines the reduced speed of adherence to the law (probability of complying with the rules) over time. The driver, who has a higher risk degree, returns to the pre-inspection procedure shortly after the inspection (red line), and the probability of his compliance with the rules decreases more quickly. On the other hand, the driver with a lower risk degree returns to the pre-inspection procedure a long time after the inspection (blue line).

Fig. 2. No-Inspection policy (NIP) results for two cases. The vertical axis in (a) represents the daily number of violating buses (DNVB) and in (b) represents the daily number of illegal passengers. The red line indicates the NIP results with an entry rate of 750 passengers per day to the terminal, and the black line shows the NIP results with an entry rate of 1500 passengers per day to the terminal. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Fig. 3. Comparison of the process of reducing law enforcement for two drivers with different risk degrees after the inspection. The red line indicates the behavior with high risk degree and the blue line indicates the behavior with low risk degree. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)
4.1.1. Results of fixed penalty policy (FPP)

In order to compare the effect of the FPP on the daily violations of terminal drivers, the simulation results of the FPP were examined and compared with no inspection policy (NIP). The simulation was performed to investigate the effects of implementing the FPP on drivers’ performance. This simulation was operated for four months plus the first five days, i.e., 125 days. Terminals are considered with high-risk degree drivers’ behavior in the simulation. The simulation results for 120 days for the number of daily violations and the number of daily illegal passengers can be seen in Fig. 4.

As can be seen in Fig. 4, the FPP has significantly reduced the number of violations compared to the NIP. In order to show the effect of the influencing factors on the daily violations of the terminals during the implementation of the FPP, each time, only one influencing factor was considered different, and simulation was performed; finally, the simulation results are given below.

4.1.2. Inspection rate effect on the rate of violation by implementing FPP

A simulation was performed to investigate the effect of inspection rate on the violation rate in FPP. In this simulation, only the daily inspection rate was doubled. The rest of the conditions are the same for the two terminals, i.e., the passenger entry rate to each terminal has a Poisson distribution at a rate of 750 passengers per day and terminals are considered with high-risk degree drivers’ behavior. The simulation results are shown in Fig. 5.

As shown in Fig. 5, the different inspection rate from the terminal significantly affects the number of violations and the daily number of offending terminal passengers.

4.1.3. Terminal drivers’ risk degree effect on the rate of violation by implementing FPP

To study terminal drivers’ risk degree effect on the rate of violation, assume two terminals, the risk factor of terminal drivers is considered equal to 1 for one terminal and equal to 0.5 for the other. The rest of the conditions are the same for the two terminals, i.e., the passenger entry rate to each terminal has a Poisson distribution at a rate of 750 passengers per day and the total number of inspections is 50 inspections per month, which is equivalent to 0.12 per hour. A simulation was performed to investigate the effect of terminal drivers’ risk degree on the violation rate in FPP. The simulation results are shown in Fig. 6.

As seen in Fig. 6, the degree of the terminal drivers’ risk significantly impacts the number of violations and the daily number of passengers in the terminal. As a result, if the inspection policy can affect the risk-taking of terminal drivers, the process of their violations will be significantly reduced.

Based on the sensitivity analysis above, generally it can be said that 1- Passenger entry rate to the terminal 2- The terminal drivers’ risk taking degree 3- Inspection rate of the terminal are three main components affecting the misconduct of terminal drivers and the resulting outbreak. Among these three components incoming passenger rate to the terminal is an exogenous variable. However, the inspection body can influence the inspection rate and the degree of risk of the terminals by presenting different policies. Then, policies for inspection and penalties of terminal drivers are presented and the results of the implementation
4.2. Variable penalty policy (VPP)

In this type of inspection and penalty policy, the inspector randomly visits the terminal over time, and during the inspection, first secretly observes the behavior of the terminal drivers for a while, and then determines the amount of penalty for the terminal according to the number of violations committed (the number of violating buses). As mentioned, amounts of penalties affect the risk degree of bus drivers. The more penalties are imposed on the offending driver, the lower the risk of terminal drivers. As shown in Fig. 7, terminal drivers initially have a high risk degree (see the blue line). Rapid forgetfulness causes more violations of terminal drivers, and in proportion to the violations a higher penalty is applied to it and as a result, drivers’ risk-taking is reduced and drivers’ violations are reduced (see green line).

Simulations were made to compare the results of the variable penalty policy (VPP) with fixed penalty policy (FPP). Simulations were performed by considering the conditions in VPP and FPP. The results of this simulation can be seen in Fig. 8.

As shown in Fig. 8, the VPP has significantly reduced the number of violations compared to the apparent inspection. Considering the long-term results, it seems that choosing VPP over FPP for city managers will have better results in preventing the spread of the disease.

5. Model development with consideration of several public passenger terminals

In urban public transportation system, several public transportation terminals serve passengers daily in different parts of the city, and the inspection organization is in charge of inspecting these terminals. This section evaluates the effect of inspection policies on several public transportation terminals in a city. For simplicity, it is assumed that there are two public transportation terminals in the city and an inspection organization with a limited number of inspectors. It is assumed that there are two approaches to assigning inspectors to inspect terminals. In the first approach of assigning inspectors the terminals which called fixed inspector assignment (FIA), inspections are carried out randomly over time but at the same inspection rate. In the second approach of assigning inspectors to the terminal which called variable inspector assignment (VIA), inspections are carried out randomly over time but at variable inspection rates. The inspection rate of the two terminals in the VIA is determined based on information about the average violations of their drivers on the days of the previous week. Thus, the inspection rate for one terminal increases with relative increases of the average violations in that terminal compared to the other terminals. Diagram 7 is the cause-and-effect diagram for VIA in which the inspection penalty follows the VPP.

The model in Diagram 7 includes two public passenger terminals and an inspection organization with a fixed rate of inspection rate. The
inspection rate of each terminal is based on the second approach of inspection allocation. Also, in this model, the inspection and penalty policy are based on the variable penalty policy (VPP). Fig. 9 compares the number of daily bus violations and the number of illegal passengers, respectively, for fixed inspector assignment (FIA) and variable inspector assignment (VIA) scenarios.

As can be seen in these two figures, the VIA reduces violations and the number of illegal passengers compared to the first approach of assigning inspections and has achieved better results.

6. Comparison and analyzing the results of different inspection policies

In this section, different scenarios are considered under the conditions of the presence of two urban public transportation terminals and an inspection organization with a certain number of inspections. Scenarios are created by combining inspection policies and inspector assignment policies. Therefore, first, inspection policies and inspector assignment models are briefly reviewed:

- First inspection policy: the policy of non-inspection of terminal companies. (NIP)
• Second inspection policy: the inspection is explicit, and the penalty is the same and fixed. (FPP)
• Third inspection policy: the inspection is covert, and the penalty is commensurate with the registered violations. (VPP)
• First policy of inspector assignment: the inspection rate is divided equally between the two terminals. (FIA)
• Second policy of inspector assignment: the division of the inspection rate between the two terminals is based on the ratio of last week’s violations of the two terminals. (VIA)

To compare and analyze the results of different scenarios, it was assumed that the passenger entry rate to each terminal has a Poisson distribution at a rate of 750 passengers per day and the total number of inspections is 50 inspections per month, which is equivalent to 0.12 per hour. The number of violations in each scenario is equal to the sum of the violations in the two terminals. The simulation is performed for 125 days and the results for the number of monthly violations and the total of four months are shown in Table 1.

As can be seen, with the implementation of inspection policies, the number of violations has significantly decreased compared to the base model. Among the various scenarios, the number of violating buses in the fourth scenario (1988) has decreased by more than 47% compared to the first scenario (3690). Also, the investigation of violating buses in the fourth scenario compared to the second and third scenarios shows a reduction of 29% and 17%, respectively.

A) Passenger arrival rate to the terminal: One of the possible scenarios that change the passenger entry rate to the terminal is the existence of days of the year, such as Christmas when the demand for daily trips of citizens increases. In this case, the modeling efficiency should be done, and the proposed scenarios should be examined. Therefore, simulation was performed by...
increasing the average passenger arrival rate from 10 passengers to 20 passengers in each period. Fig. 11 shows changing the passenger entry rate to the terminal on the total number of violations for the four proposed scenarios. Based on what can be seen in Fig. 11, increasing the passenger entry rate to the terminal increases the number of terminal violations. If not inspected (red line), this process will continue until all the buses violate and carry passengers to their total capacity. However, in all values of the passenger entry rate to the terminal, scenario four, namely the scenario of combining covert inspection policy and assigning variable inspector (VFP + VIA) to a reasonable extent, prevents the increase in the number of violations and maintains its superiority over other scenarios.

B) Inspection rate: The second issue of the analysis is the decision to increase the number of inspectors and increase the inspection rate. Most inspection agencies seek to examine the impact of increased inspection rates on violations. The number of inspections was considered 50 times a month in the previous sections. In this part, simulations were performed for the number of inspectors from 25 to 75. The simulation results can be seen in Fig. 12. As shown in Fig. 12, increasing the inspection rate reduces the number of violations in all inspected scenarios. Also, in

| Scenario number | Inspection and penalty policy + Inspector Assignment policy | First month | Second month | Third month | Fourth month | Total |
|-----------------|------------------------------------------------------------|-------------|--------------|-------------|--------------|-------|
| Total number of offending buses | Scenario 1 NIP | 960 | 914 | 944 | 904 | 3690 |
| | Scenario 2 FPP + FIA | 724 | 680 | 726 | 686 | 2795 |
| | Scenario 3 VPP + FIA | 600 | 604 | 611 | 585 | 2381 |
| | Scenario 4 VPP + VIA | 506 | 512 | 496 | 483 | 1988 |
| Total number of illegal passengers | Scenario 1 NIP | 4156 | 4172 | 7289 | 4196 | 16815 |
| | Scenario 2 FPP + FIA | 3732 | 3596 | 3891 | 3793 | 15014 |
| | Scenario 3 VPP + FIA | 3279 | 3367 | 3330 | 3374 | 13351 |
| | Scenario 4 VPP + VIA | 2876 | 2887 | 2940 | 2840 | 11545 |
all inspection rate values, the fourth scenario (VIP + VIA) compared to other inspection scenarios and fines could make the most of the increased inspection to reduce violations.

C) Drivers’ risk-taking rate: The third issue that transportation companies consider is the effect of terminal drivers’ risk-taking characteristics on the rate of violations. To this end, simulations were performed with a risk-taking rate ranging from zero...
(completely risk-averse) to 1 (fully risk-averse). The simulation results can be seen in Fig. 13. As can be seen, as the risk of drivers increases, the number of terminal violations in all scenarios increases. However, scenario four (VIP + VIA) was able to show its superiority over other scenarios in preventing the growth of violations in all values of the risk parameter.

D) Schedule of buses: Finally, the fourth issue that is very important is the occurrence of accidents such as traffic jams in the city, weather conditions such as rain or ice, and the breakdown of buses in the middle of their route. The occurrence of these accidents affects the departure time of terminal buses. In proportion to the rate of accidents per day, the schedule of arrival and departure of buses in the terminal, which is quite regular and every 15 min, is delayed. Meaningfully, simulations were performed for the number of daily delays in the departure of terminal buses. The simulation results can be seen in Fig. 14. As can be seen in Fig. 14, the number of violations increases with the delay in the movement of terminal buses. In explaining this issue, it can be said that due to the accident and the delay in the bus movement, the population of passengers present at the terminal has increased, and conditions are provided for drivers to commit violations. The proposed policy to transport companies to avoid delays is to consider replacement buses in an accident. As shown in Fig. 14, in this parameter, scenario four showed its superiority in reducing the violations compared to other scenarios.

According to the sensitivity analysis performed on the proposed model, it can be concluded that the results obtained are acceptable in most environmental conditions.

As the research questions mentioned in the introduction, this study sought to provide a dynamic systems model of the problem of disease outbreaks in transport companies and provide policies to improve resilience against epidemic disasters. Designing a comprehensible and expandable model based on systems theory can create a comprehensive understanding of the investigated problems and help design policies whose implementation will favor the system. Although the purpose of this study was not to present a complex model, the mathematical relationships among the model’s components indicate the complexities in modeling. The sensitivity analysis can show these relationships’ accuracy and the proposed model’s validity.

8. Conclusions and suggestions for future studies

The influential role of health protocols in preventing the spread of the pandemic has led governments to seek their best implementation in society. Inspection is one of the policies that can be very effective in better implementation of these protocols. However, the limited resources available for inspections and the policy to enforce them, reduce the impact of inspections. Lack of social distance in public vehicles, which is the source of the movement of public transportation terminals, is one of the leading causes of epidemic diseases. This study examined and evaluated some of the inspection policies of urban public passenger
terminals for the proper implementation of health protocols.

System complexity (such as interactions between inspectors, bus drivers, and passengers), nonlinear relationships between system components (e.g., the effect of penalties on drivers’ level of risk), problem dynamics (such as changes in drivers’ risk behavior over time), and the randomness of some components (such as passenger arrival time at the terminal) caused this study to use the dynamic system approach to model the current state of the existing system (base model). By presenting the simulation results, the main factors of increasing violations in these terminals were introduced. These factors are the condition of the terminal congestion, the risk behavior of the terminal drivers, and the inspection rate that is done from the terminal. By introducing two types of policies, including fixed penalty policy (FPP) and variable penalty policy (VPP) and simulating them, it was shown that the VPP performs much better than the FPP. Then, the model extended by considering several passenger transportation terminals simultaneously, presenting two policies for inspector assigning to terminals, including fixed inspector assignment (FIA) and variable inspector assignment (VIA). The results indicate that the combining “VPP” and “VIA” has a good performance in the inspection.

Although in this research, an attempt was made to identify and consider most of the practical components to reduce violations in public transportation terminals, ideas can be proposed for future studies. The presented model can be expanded and complicated by analyzing the cost of adding an inspector or cultural advertising to reduce passenger arrivals and encourage legal terminals. Also, the process of recognizing drivers from the time and day of the inspectors’ inspection can be added to the model by a negative feedback loop. Finally, competition between terminals is also another issue that can be addressed. Using methods such as game theory to examine terminal ticket pricing can benefit policy-making terminals competing with each other.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.
Appendix A. Equations of base model’s flow diagram
Diagram 4. Flow diagram of FPP.

Diagram 5. Causal loop diagram of the VPP.
Diagram 6. Flow diagram of VPP.
Diagram 7. Causal loop diagram of combination VIA and VPP.

\[
BP(t) = BP(t - dt) + (PDR - BPER) \times dt \\
\text{INIT } BP = 0 \\
\text{INFLOWS:} \\
PDR = \text{PULSE}((\text{IF}(TP>25) \text{ THEN } (25) \text{ ELSE } (TP)),2,3)) \\
\text{OUTFLOWS:} \\
BPER = BPED \\
DNIP(t) = DNIP (t - dt) + (IRIP - APCR) \times dt \\
\text{INIT } DNIP = 0 \\
\text{INFLOWS:} \\
IRIP = \text{IF}(PDR-15)=0 \text{ THEN}(PDR-15) \text{ ELSE } (0) \\
\text{OUTFLOWS:} \\
APCR = \text{PULSE}(DNIP),167,168) \\
DNVB(t) = DNVB (t - dt) + (IRVB - BVCR) \times dt \\
\text{INIT } DNVB = 0 \\
\text{INFLOWS:} \\
IRVB = \text{IF}(PDR-15)=0 \text{ THEN } (1) \text{ ELSE } (0) \\
\text{OUTFLOWS:} \\
BVCR = \text{PULSE}(DNVB),167,168) \\
TP(t) = TP (t - dt) + (PAR \times PDR \times EDR) \times dt \\
\text{INIT } TP = 0 \\
\text{INFLOWS:} \\
PAR = DPE \\
\text{OUTFLOWS:} \\
PDR = \text{PULSE}((\text{IF}(TP>25) \text{ THEN } (25) \text{ ELSE } (TP)),2,3)) \\
EDR = EDD \\
BPED = \text{PULSE}(BP,5,3) \\
DPE = \text{POISSON} (10) \times PD \\
EDD = \text{PULSE} (1000,167,168) \\
PD = \text{GRAPH} (\text{time1}) \\
\text{time1} = (\text{time MOD } 168)
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