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Study on the Impact of Health Condition Registration and Temperature Check on Inbound Passenger Flow and Optimisation Measures in a Metro Station during the COVID-19 Pandemic

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ABSTRACT
The Guangzhou Metro Authority implemented health condition registration and temperature checks to curb the spread of the virus during the COVID-19 pandemic. However, it is important to investigate how these measures may have impacted the get-through efficiency and whether they caused the increased crowding at entrances and the station hall. To address these questions, simulation models based on the T Station were developed using AnyLogic. The model compared the get-through efficiencies with and without the anti-epidemic measures, while also analysing the risk of crowding at entrances and within the station hall after their implementation. Results revealed an increase in the number of passengers unsuccessfully passing through the check-in gate machines from 15% to 53% within 5 minutes, and 10% to 45% within 10 minutes when the anti-epidemic measures were in place. It was also observed that some entrances experienced significant crowding. Three measures were simulated to find effective ways to increase the get-through efficiency and mitigate the crowding – increasing the distance between security and health checks, utilising automatic infrared thermometers, and arranging volunteers or staff to assist with the registration process. The results demonstrated that using automatic infrared thermometers instead of handheld forehead thermometers proved to be effective in improving passenger efficiency and alleviating crowding at entrances and within the station hall.

KEYWORDS
temperature check; health condition registration; metro station; COVID-19; passenger flow; safety; optimisation measures.

1. INTRODUCTION

1.1 Background

After the breakout of the COVID-19 pandemic at the beginning of 2020, public transportation, with the metro system included, was seriously impacted around the world. The ridership of the metro system in most cities showed a dramatic decrease after the epidemic broke out [1–3]. Some metro systems or parts of the metro stations were even closed during the worst period of the pandemic [4, 5]. From May 2020, as the pandemic situation has gradually been brought under control in China, closed metro stations were reopened for the public. However, various anti-epidemic measures and contagion-prevention policies or measures were still adopted to ensure the safety of passengers [6, 7]. Research proved that traveller screening is an effective way to stop or slow the spreading of infectious viruses [8, 9]. Thus, measures such as temperature checks and health condition registration were implemented at the entrances of metro stations in Guangzhou City, China. Every passenger who wanted to enter a metro station in Guangzhou was required to accept the temperature check and show the health QR code, if they did not have one, they were asked to get registered for their health condition (i.e. health status declaration). The information about T Station and its anti-epidemic measures is introduced in detail below.

1.2 T Station and anti-epidemic measures

T Station is situated in the downtown of Guangzhou, a bustling city in southern China. Serving as a vital transportation hub, it connects three metro lines, making it a significant focal point for commuters. The vibrant business district surrounding T Station adds to its constant hustle and bustle, as depicted in *Figure 1*. By examining the passenger flow statistics, it was observed that on 31 December 2016, 31 December 2017 and 17 August 2018, the number of inbound, outbound and transfer passengers at T Station reached 617,100, 844,000 and 846,000, respectively. These figures demonstrate the station's high level of congestion. T Station stands out as one of the busiest and most crowded metro stations not only in Guangzhou but also across China. Managing the flow of passengers presents significant challenges due to the dense crowds, particularly during peak hours in the morning and evening, as well as holidays.

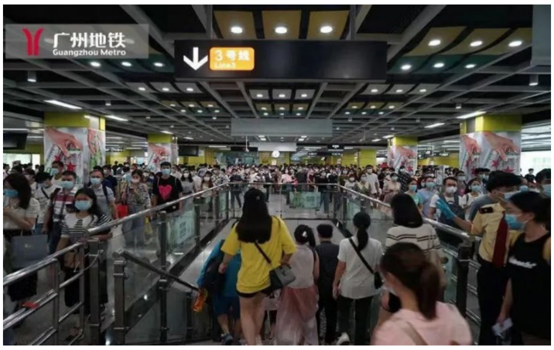

Figure 1 – The crowd during peak hours in T Station of Guangzhou Metro

During the COVID-19 pandemic, Guangzhou Metro and T Station implemented several measures to ensure the safety of passengers. The following measures were specifically put in place:

1) Mandatory mask usage: All passengers entering any metro station were obligated to wear a mask throughout their entire journey. This requirement aimed to reduce the risk of transmission and prioritise the health of both passengers and staff.
2) Health QR code verification: Before entering any metro station, all passengers had to present their "health QR code". This code, exemplified in *Figure 2*, served as proof of the individual's health status. If someone did not possess a health QR code, they had to apply for one, which involved registering their health condition. Personal applicants could conveniently obtain the health QR code on their mobile devices. The application process entailed providing personal information, disclosing health details and reporting their travel history over the past 15 days.
3) All passengers entering a metro station had to undergo temperature screening. Metro staff utilised forehead thermometers, as depicted in *Figure 3*, to measure the temperature of each individual. Only passengers with normal temperatures were permitted to enter the metro stations. In the event of passengers displaying abnormal temperatures, they would receive temporary isolation, and then be provided with health advice or medical treatment from designated medical institution. This ensured that any potential health concerns could be promptly investigated and treated.

Figure 2 – A typical health QR code widely used in mainland China during the COVID-19 pandemic

Figure 3 – Temperature check using hand-held forehead thermometers in a station of Guangzhou Metro during the COVID-19 pandemic (Source: http://m.xinhuanet.com)

These measures were implemented to mitigate the spread of COVID-19 and ensure a safer commuting experience for all passengers utilising T Station, as well as other stations of Guangzhou Metro.

1.3 Research issues

Based on on-site measurements, it has been determined that the average duration for passengers to undergo temperature screening is approximately 5 to 8 seconds. Individually, this time frame is relatively short. However, certain stations within the Guangzhou Metro experience a substantial influx of passengers, particularly during the morning and evening peak hours. Conducting temperature checks for every inbound passenger during these busy periods can easily result in significant congestion at the temperature-checking stations. Additionally, certain passengers, such as the elderly or those who do not use smartphones, may not possess a health QR code and will be required to to get registered, i.e., sign a health declaration or apply for a health QR code on-site. The declaration or application process typically takes around 1 to 2 minutes to complete, further exacerbating congestion issues.

Undoubtedly, anti-epidemic measures implemented to combat the COVID-19 pandemic were crucial for ensuring passenger safety. However, it is important to acknowledge that these measures inevitably result in increased time requirements for passengers to enter the metro stations, consequently raising the risk of congestion at the entrances [10]. Such congestion is unfavourable in terms of anti-epidemic efforts as it leads to people standing close to each other, thereby heightening the potential for jostling or stampede accidents. Moreover, the close gathering of passengers at the entrances amplifies the risk of COVID-19 transmission. Therefore, it becomes imperative to conduct a thorough investigation into the impact of these anti-epidemic measures on the inbound passenger flow at metro stations to identify appropriate optimisation strategies [11]. Only through this approach can the safety of passengers and the operational efficiency of metro stations be effectively guaranteed.

2. LITERATURE REVIEW

The outbreak of the COVID-19 pandemic has presented significant challenges for the management of passenger flow in various public transportation settings, including metro stations, bus stations and other transport hubs. Relevant studies have evaluated the impacts of the COVID-19 pandemic on passenger flow and safety of these transport hubs and explored the key considerations, best practices and emerging technologies used in passenger flow management during the COVID-19 pandemic.

The COVID-19 pandemic has profoundly impacted passenger flow in public transportation hubs worldwide. Stringent measures such as lockdowns, social distancing and travel restrictions have significantly reduced the number of commuters and travellers, leading to a drastic decline in public transportation usage [12–17]. Studies have reported substantial drops in passenger volume, with certain modes of transportation experiencing up to 60% decrease compared to pre-pandemic levels [18]. These changes have had severe financial implications for transportation authorities and operators, causing revenue losses and budgetary challenges, as well as challenges in providing safe travel for passengers [19]. Many measures have been studied, discussed and implemented to ensure the normal operation of transport hubs during the coronavirus pandemic and to ensure the safety of passengers.

Given the metro system's significance as a vital public transportation mode with a substantial volume of passengers in urban areas, the metro station management authorities in different cities around the world have implemented corresponding epidemic prevention measures during the COVID-19 pandemic. In China, metro stations have implemented strict health and safety protocols. This includes mandatory temperature checks at entry points, the use of face masks and hand sanitisation [10]. Additionally, digital signage and announcements have been used to educate passengers about safety measures, encourage physical distancing and popularise knowledge on infection prevention [20, 21]. To manage passenger flow, metro stations have implemented crowd control measures. This involves regulating the number of passengers allowed in the station at a given time and marking designated waiting areas with social distancing. Some stations have implemented one-way flow systems or separate entrances and exits to prevent congestion, and real-time monitoring of passenger volumes has also been carried out to ensure compliance with capacity limits. Internationally, metro systems have also adopted similar approaches to manage passenger flow during the pandemic. Many cities have implemented mandatory mask-wearing policies and provided hand sanitisers within closed public spaces, including metro stations [22]. Furthermore, some countries have encouraged contactless payment methods to minimise physical contact and reduce the risk of transmission [23]. Stations have also increased the frequency and intensity of cleaning and disinfection procedures, focusing on metro vehicles and high-touch surfaces such as handrails and ticketing machines [24, 25]. Certain countries have introduced face mask-wearing detection techniques to protect people against coronavirus in metro stations [26, 27].

It is necessary to conduct research and discussions on the potential impact of epidemic prevention measures taken in metro stations on passenger flow management. Scholars have researched the potential effects of epidemic prevention measures, mainly crowd control (like social distancing) implemented in metro or railway stations. Lee et al. analysed passenger flow and behaviour at Birmingham New Street railway station during COVID-19 by using the SIMUL8. The result shows that even with fewer ticket machines, overcrowding was unlikely pre-COVID. COVID-19 measures led to shorter queues and reduced system time due to fewer passengers. Suggestions for crowd management include smartphone ticket purchases, sensor-based gates and one-way passenger flow [28]. Passenger flow simulations were used by Blide et al. to assess whether social distancing policies could be implemented properly in stations, with small, medium and large traffic flows. They found that a few of the highest-demand stations, such as intermodal hubs, have great difficulties in achieving the desired social distancing measures [29]. Lu et al. evaluated the effectiveness of strategies including controlling the flows of inbound and outbound passengers in the station, setting route guidance in the crucial areas, and shortening the interval time of the train, results show these strategies help reduce the maximum passenger density and the average travel time [30]. The effectiveness of social distancing policy and other measures in the metro or rail system in cities like Bangkok [31], Seoul [3, 32], New York [33] and other cities were studied as well.

Previously, studies have focused on analysing social distancing measures as a means of controlling passenger flow in subway stations during the COVID-19 pandemic. However, limited information is available regarding the potential effects of health registration and temperature checks on the inbound passenger flow, specifically at Guangzhou Metro T station. To address this gap, this article aims to investigate and analyse the possible impact of these measures on station passenger flow management. Furthermore, the study will explore potential strategies for enhancing the effectiveness of these measures and improving overall passenger flow management at the station.

3. METHOD

3.1 Software selection

As discussed above, simulation is a widely used method to solve problems related to passenger flow in different places, thus the passenger flow simulation will be used to analyse the effects of anti-epidemic measures and optimisations measures.

For developing passenger flow or queuing models we can use the following programs: AnyLogic, Arena, Bizagi Modeler, Business Studio, Enterprise Dynamics, ExtendSim, Flexsim, GPSS W, Plant Simulation, Process Simulator, Rand Model Designer, Simio Simul8 [34]. Comparisons for these simulation programs have been made by Yakimov et al. [35]. AnyLogic is a simulation software that is widely used in the simulation of manufacturing, road traffic and logistics, also it can be used to simulate the passenger flow or crowd in public places such as stations or airports [36–38]. Since AnyLogic can provide a graphical interface for modelling without carrying out field experiments, it is widely applied. AnyLogic can also be adapted to the simulation of pedestrian movement or the passenger flow because Pedestrian Library can provide various blocks, including PedSource, PedSink, PedGoTo, PedService, PedWait, PedSelectOutput, PedEnter, PedExit to simulate the generation, movement, route selection and leave of passengers [39, 40]. Thus, AnyLogic will be used to establish passenger flow simulation models to study the effects of anti-epidemic measures as well as the effectiveness of optimisation measures in this article.

3.2 Building structure of T Station

The building structure of T Station is shown in *Table 1*. Among them, the shared station halls of Line 1, Line 3A and Line 3B are located on the first floor underground. The platforms of Line 1, Line 3A and Line 3B are located on the 2nd and 3rd floors underground, respectively. Between the 1st floor and the 3rd floor underground, there are two mezzanines, i.e. the #1 mezzanine and #2 mezzanine.

Table 1 – The building structure of T Station

Layer	Buildings	Facilities
Ground surface	Streets	Entrances/Exits
1st floor underground	Shared station hall	ATMs, ticket booths, automatic ticket machines, gates, security checking machines, etc.
2nd floor underground	Line 1 platform	Escalator and elevators, platform, benches
Mezzanine	Equipment room and escalator platform	Escalator and stairs (connecting Line 3 platform and station hall)
3rd floor underground	Platforms of Line 1, Line 3A and Line 3B	Escalators and elevators, platforms, benches

The station hall of T Station features a unique, irregular cross shape. This shared station hall serves as a common area for passengers travelling on Line 1, Line 3A and Line 3B, as illustrated in *Figure 4*.

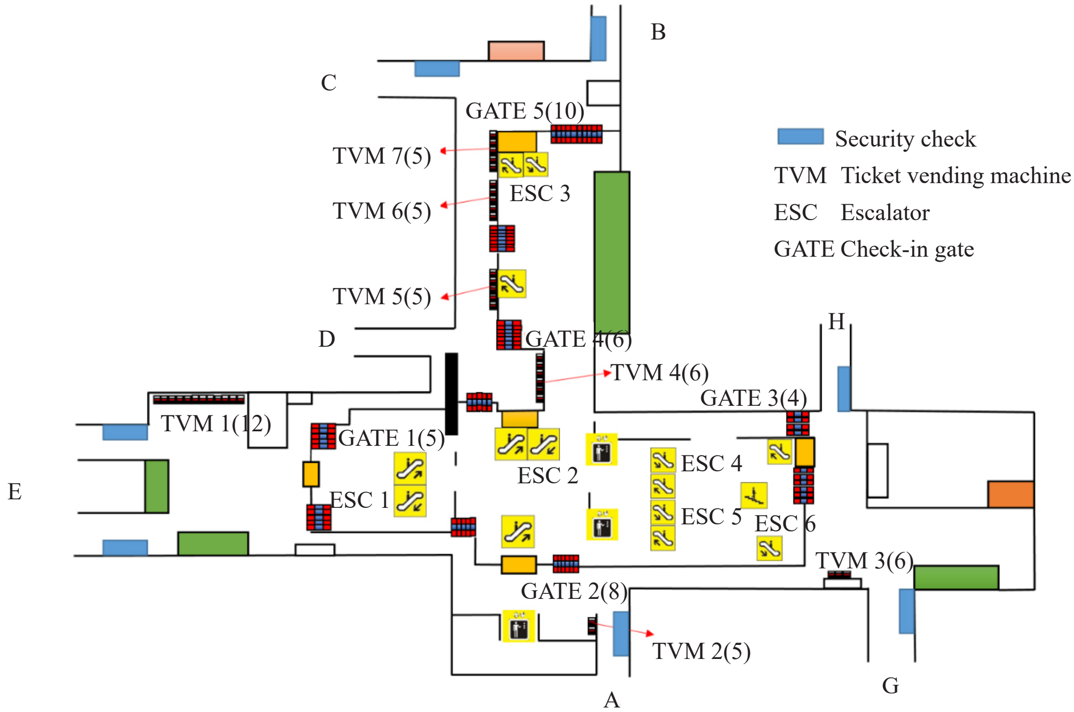

Figure 4 – The station hall shared by Line 1, Line 3A and Line 3B

Figure 4 highlights the presence of three entrances/exits, namely Entrance B (4.0 m wide), Entrance C (4.0 m wide) and Entrance D (4.0 m wide), which are interconnected with the station hall of Line 1. Additionally, the station hall of Line 3A and Line 3B features four entrances/exits, including Entrance A (6.0 m wide), Entrance E (6.0 m wide), Entrance G (5.3 m wide) and Entrance H (5.0 m wide).

Figure 4 provides additional information regarding the abbreviations used. In this context, “TVM” represents the ticket vending machine, “ESC” refers to the escalator and “GATE” signifies the ticket check-in gate machine. The numbers in brackets after each marking indicate the quantity of equipment present in the respective locations. It is important to note that, for inbound passengers, only the escalators that lead downstairs are depicted. Additionally, the stairs connecting the shared station hall and the platforms are marked as ESC 1 to ESC 6.

3.3 Routes of inbound passengers

Figure 5 illustrates the typical route followed by inbound passengers on normal days, while *Figure 6* displays the modified route during the COVID-19 pandemic. Under normal circumstances, temperature checks for each passenger typically require 5 to 8 seconds. Conversely, based on on-site investigations, the health condition registration process can take approximately 1 to 2 minutes.

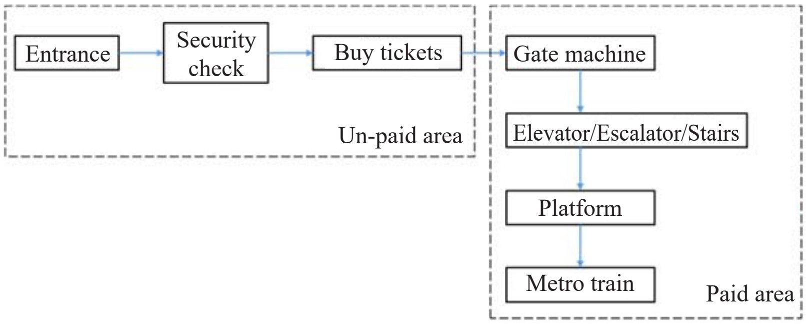

Figure 5 – Route of inbound passengers during normal days

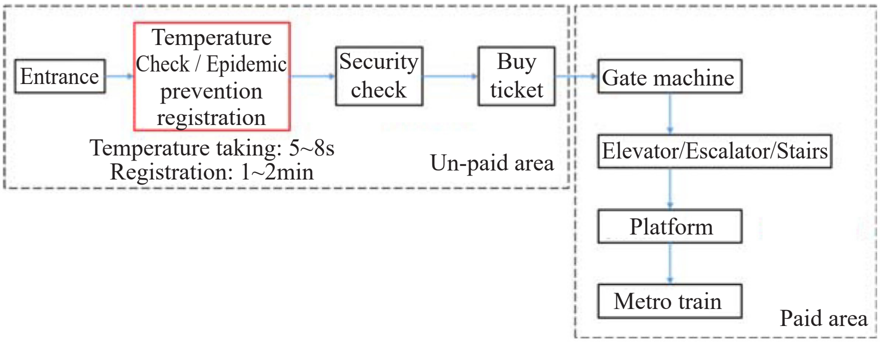

Figure 6 – Route of inbound passengers during the COVID-19 pandemic in T Station

3.4 Passenger route design in AnyLogic

Figures 5 and 6 provide visual representations of the passenger flow process at T Station. According to the figures, passengers are required to undergo health condition registration, temperature checks and security checks before entering the shared station hall. Subsequently, passengers have two options depending on their ticketing method: those who require recyclable tickets will utilise the ticket vending machines, while those with metro cards or e-tickets can proceed directly to the check-in machines. Once checked in, all passengers proceed to the platform by either using the escalators or the stairs.

In the AnyLogic model, it is assumed that a total of 79 passengers will enter through the entrances every minute. The model parameters for the passengers are configured as follows: the diameters of the passengers' bodies follow a uniform distribution with a range of 0.4 to 0.5 meters, and their initial moving speeds are uniformly distributed between 0.5 and 1.8 meters per second. Additionally, the passengers' comfortable moving speeds are also uniformly distributed, ranging from 0.8 to 1.3 meters per second.

During the COVID-19 pandemic, the total time required for passengers to enter a metro station encompasses several components. These include the time for temperature check (T1), the time for certain passengers to complete registration (T2), the duration of the security check (T3), the time for specific passengers to obtain a recyclable ticket from the vending machine (T4) and the duration to pass through the gate machine (T5). The durations for each period are set as follows:

– T1 is the average time required to complete a temperature check that is estimated to be between 5 to 8 seconds. To simplify the model, an average time of 6.5 seconds is set as the duration for the temperature check. Additionally, it is assumed that 96% of the passengers entering from each entrance already possess health QR codes.
– For T2, passengers who do not have a health QR code are required to apply for one, which takes approximately 3 to 4 minutes on average. In the simulation model, an average time of 3.5 minutes is set for this process. It is assumed that 4% of the passengers at each entrance do not possess health QR codes and therefore need to complete the health declaration and registration process with the assistance of the station staff.
– For T3, the time required to complete the security check follows a uniform distribution with a range of 3.0 to 5.0 seconds. It is assumed that 70% of the passengers entering from each entrance are carrying luggage and are subject to security checks in the model.
– T4 represents the time it takes for a passenger to obtain a recyclable ticket from the ticket vending machine. In the model, this time duration follows a normal distribution with a mean of 12.36 seconds and a standard

deviation of 42 seconds. According to statistics provided by the Guangzhou Metro Authority, it is estimated that 35% of passengers need to purchase a recyclable ticket after completing the security check.
- T5 is the time required for each passenger to pass through the check-in gate machine. In the model, this time duration is set to a constant value of 5 seconds, which represents the average time it takes for passengers to pass through the fare gate.

Table 2 provides information regarding the number of passengers entering through different entrances and the proportions of passengers using each ticket vending machine, check-in gate machine and escalator. Passengers typically tend to choose the facilities that are closest to their entrance.

Table 2 – The proportion of users of different TVM, gate machines and escalators

Entrance	Number of entering passengers each minute	TVM	Gate machines	Escalators
A	8	TVM2 (35.00%)	GATE2 (100%)	ESC2 (30%), ESC4 (35%), ESC5 (35%)
B	8	TVM6 (12.25%) TVM7 (22.75%)	GATE5 (100%)	ESC3 (40%), ESC4 (60%)
C	10	TVM6 (12.25%) TVM7 (22.75%)	GATE5 (100%)	ESC3 (40%), ESC4 (30%), ESC5 (30%)
D	13	TVM4 (17.50%) TVM5 (17.50%)	GATE4 (100%)	ESC2 (40%), ESC4 (30%), ESC5 (30%)
E	13	TVM1 (35.00%)	GATE1 (100%)	ESC1 (70%), ESC2 (30%)
G	7	TVM3 (35.00%)	GATE2 (60%) GATE3 (40%)	ESC2 (60%), ESC4 (16%), ESC5 (16%), ESC6 (8%)
H	12	TVM3 (35.00%)	GATE2 (60%) GATE3 (40%)	ESC2 (40%), ESC4 (20%), ESC5 (20%), ESC6 (20%)

Figure 7 depicts the actual route followed by inbound passengers entering through Entrance E, while *Figure 8* displays the simulated route in the model. It is worth noting that passengers entering from other entrances have similar routes when they enter the metro station. The route for passengers entering from other entrances is also set similarly to the route followed by passengers entering from Entrance E in the model.

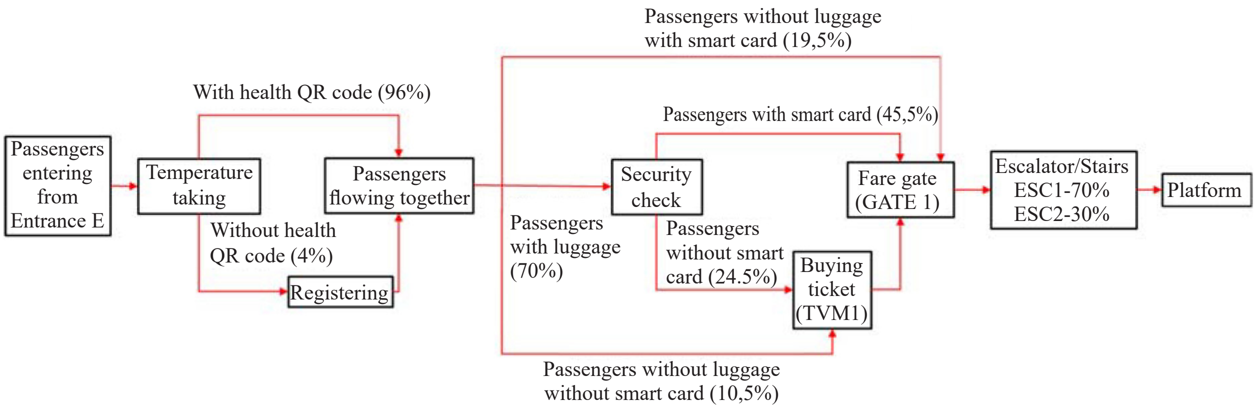

Figure 7 – The actual entering process of passengers from Entrance E

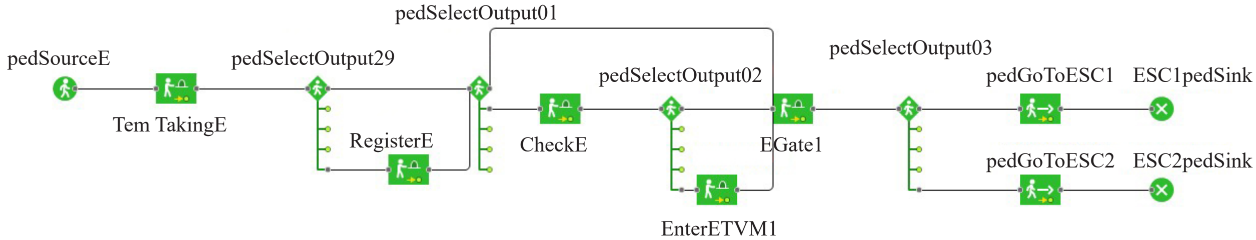

Figure 8 – The logic diagram of passengers from Entrance E in the AnyLogic model

3.5 Simplification and hypotheses

When developing the passenger flow model for the T metro station, several simplifications have been made for the sake of focus and efficiency. These simplifications are as follows:

1) The model primarily focuses on the impacts of anti-epidemic measures on inbound passenger flow. As a result, outbound passengers are not considered in the model. The assumption is that inbound and outbound passengers utilise separate escalators/stairs and gate machines, with inbound passengers occupying one side of the entrance.
2) Once passengers have their tickets checked at the gate machines, the model does not account for their activities beyond that point. Specifically, their movements after using the nearest escalator or stairs to descend to the platform are not considered in the model.
3) After passengers pass through the gate machines, their activities following the use of escalators or stairs to reach the platforms are not taken into account in the model.

These simplifications have been made to streamline the analysis and focus on the specific aspects related to the impacts of anti-epidemic measures on inbound passenger flow at the T metro station.

3.6 Established model

Figure 9 presents the inbound passenger flow model created using AnyLogic, which is based on the actual layout of the T station. The model accurately reflects the configuration of the station hall, the number of various facilities and the route taken by passengers during the entering process. The model has been designed to closely resemble the actual situation to ensure its accuracy and realism.

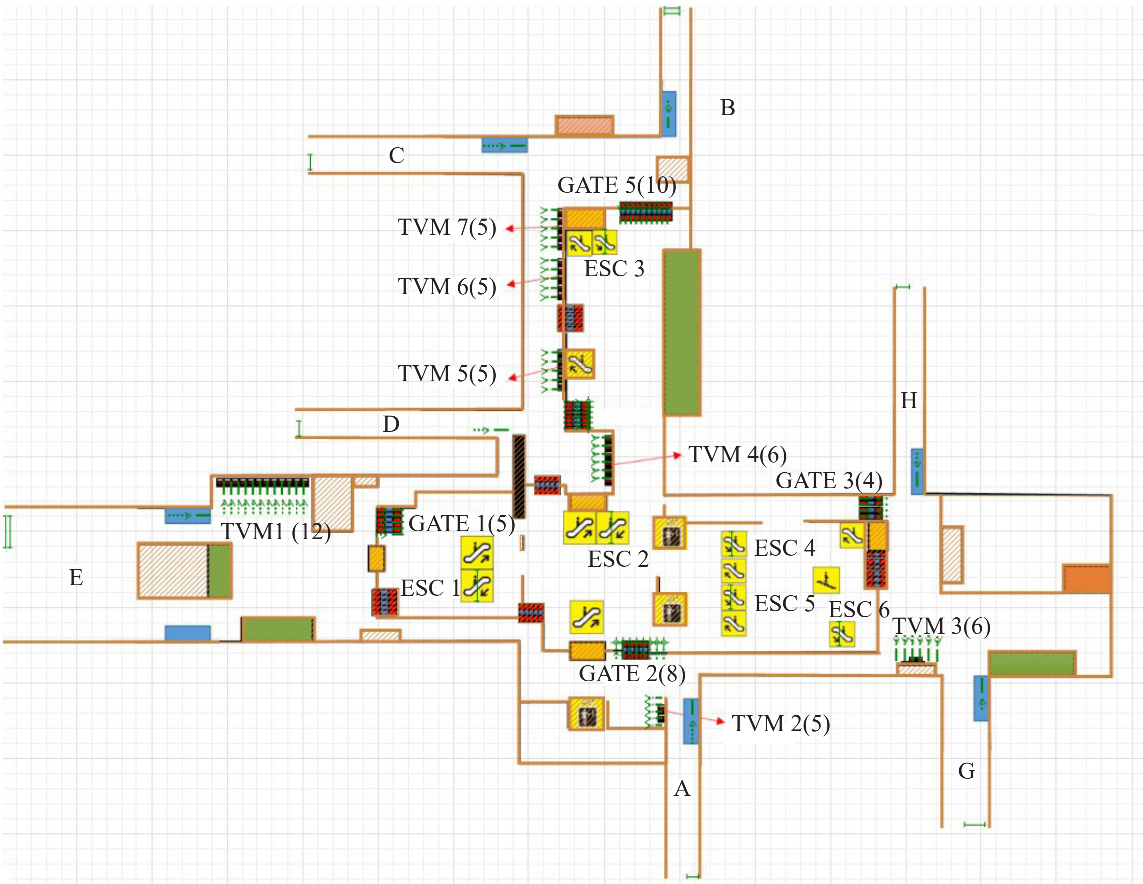

Figure 9 – Established basic AnyLogic model based on T station

3.7 Model accuracy analysis

Due to the discontinuation of anti-epidemic measures following the conclusion of the COVID-19 pandemic, it was not possible to verify the model using actual passenger flow data or conduct field investigations of congestion. However, it is important to note that the model's development was based entirely on the structural design and layout of T Station, while the parameters concerning passenger behaviour were obtained from statistical surveys. Furthermore, the simulation results demonstrate qualitative consistency with the station staff's understanding of inbound passenger flow characteristics during the epidemic period, including congestion locations and reduced efficiency. Therefore, considering these factors, the calculated results of the model can be regarded as relatively reliable.

4 RESULTS ANALYSIS AND DISCUSSION

4.1 Crowd density

The simulation study provides valuable insights into crowd density patterns at the 5-minute mark, comparing scenarios with and without the implementation of anti-epidemic measures. *Figure 10* presents the crowd density distribution when no anti-epidemic measures are employed, while *Figure 11* illustrates the crowd density under the condition where measures, such as health condition registration and temperature check, are implemented.

Upon examining *Figure 10*, it becomes apparent that the crowd densities at each entrance and within the station hall remain consistently below 1 person/m^2. This indicates that in the absence of anti-epidemic measures, no noticeable crowding occurs. Passengers can move through the entrances and the station hall without significant congestion or impediments to their progress. However, when the anti-epidemic measures are applied, including health condition registration and temperature checks, a discernible change in crowd density becomes

Figure 10 – The crowd density (persons/m^2) at 5 minutes after the simulation begins under the condition that no anti-epidemic measures are taken

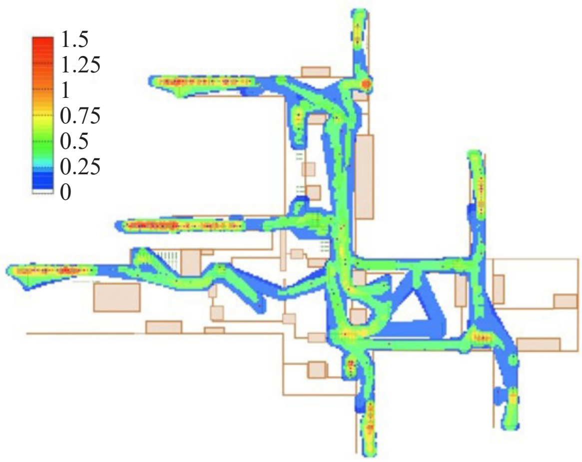

Figure 11 – The crowd density (persons/m^2) at 5 minutes after the simulation begins under the condition that anti-epidemic measures are taken

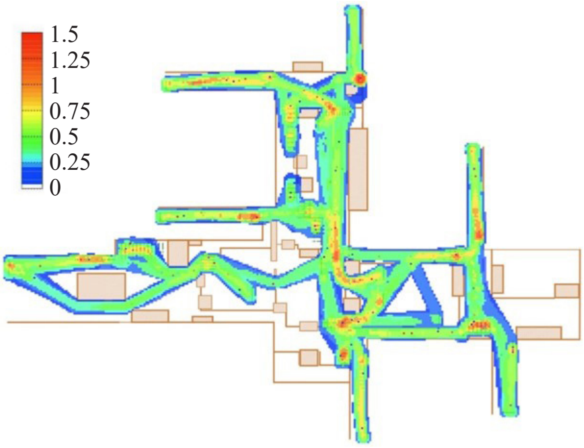

Figure 12 – The crowd density (persons/m^2) at 10 minutes after the simulation begins under the condition that no anti-epidemic measures are taken

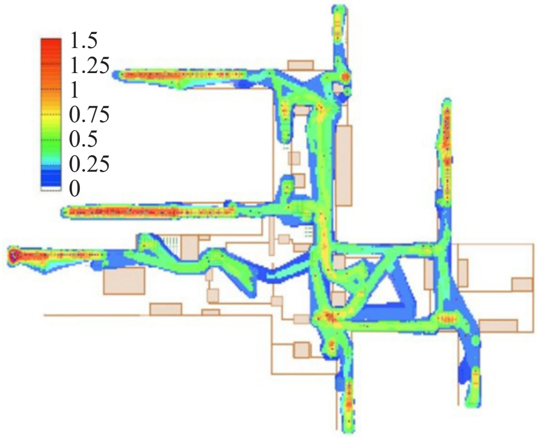

Figure 13 – The crowd density (persons/m^2) at 10 minutes after the simulation begins under the condition that anti-epidemic measures are taken

evident at Entrances C, D and E within just 5 minutes. The crowd densities in these areas surge to approximately 1.5 persons/m^2. This increase in crowd density suggests that the implementation of these measures leads to notable crowding at these specific entrances in just 5 minutes after the simulation begins. *Figure 12* illustrates the crowd density 10 minutes into the simulation without the implementation of anti-epidemic measures, while *Figure 13* showcases the crowd density at the same time when the measures are put in place. Upon reviewing *Figure 12*, it is evident that there is still no observable crowding occurring at each entrance and within the station hall after 10 minutes without the anti-epidemic measures. Passengers can navigate through these areas without experiencing significant congestion. However, the situation changes when anti-epidemic measures are adopted. *Figure 13* demonstrates a notable increase in crowding at Entrances C, D, E and H after the same 10-minute duration. At these entrances, the waiting queues of passengers can extend up to 20 meters, indicating a significant accumulation of individuals. The implementation of anti-epidemic measures appears to intensify the level of crowding, potentially posing challenges to passenger flow and safety within these specific areas.

4.2 Entered passenger number

The simulation results provide insight into the number of passengers passing through various gate machines within 5 and 10 minutes, as outlined in *Tables 3 and 4*. It is evident that the implementation of anti-epidemic measures leads to a reduction in the number of passengers passing through these gates. Within the first 5 minutes, the decrease ranges from 15% to 53%, and within 10 minutes, it ranges from 10% to 45%. These findings highlight a significant decline in the efficiency of each gate machine after the adoption of anti-epidemic measures.

Moreover, the decrease in passenger flow efficiency and the subsequent increase in congestion at the entrances and connecting areas within the station hall pose challenges to both pandemic prevention efforts and the smooth passage of passengers. This situation emphasises the need to reassess the current anti-epidemic measures and explore potential strategies that can enhance passenger throughput while maintaining effective prevention measures. By optimising the balance between safety and efficiency, metro station managers can strive to alleviate congestion and streamline the passage of passengers. It is crucial to find innovative solutions that maintain strict anti-epidemic protocols while minimising the impact on passenger flow.

Table 3 – The number of passengers entered through different check-in gate machines in 5 minutes

Gate machine	The number of passengers entered		$(n_1-n_2)/n_1$ (%)
	Without anti-epidemic measures n_1	With anti-epidemic measures n_2	
GATE 1	53	25	53
GATE 2	65	55	15
GATE 3	26	21	19
GATE 4	57	29	49
GATE 5	68	49	28

Note: "anti-epidemic measures" in this table mean temperature check and health condition registration.

Table 4 – The number of passengers entered through different check-in gate machines in 10 minutes

Gate machine	The number of passengers entered		$(n_3-n_4)/n_3$ (%)
	Without anti-epidemic measures n_3	With anti-epidemic measures n_4	
GATE 1	119	65	45%
GATE 2	162	146	10%
GATE 3	69	43	38%
GATE 4	107	66	38%
GATE 5	169	125	26%

Note: "anti-epidemic measures" in this table mean temperature check and health condition registration.

5. OPTIMISATION MEASURES AND EFFECTIVENESS DISCUSSIONS

5.1 Optimisation measures

As discussed above, temperature checks and health condition registration at the entrances of T Station will prolong the entering time of passengers, so crowds easily form at the entrances. To reduce the number of people gathered at the entrances due to temperature check and health condition registration, 3 different possible measures are proposed here and the effectiveness of them are tested by adding modifications to the original AnyLogic model. Three proposed possible measures are listed below:

Optimisation measure #1: Lengthen the distance between security and health checks. In the original model, the temperature check and registration are quite close to the security check, only 1.5 m in distance. In the model modified with Measure #1, the distance between temperature check, health condition registration and security check is prolonged to 10 m.

Optimisation measure #2: Use an automatic infrared thermometer to take the passengers' temperature instead of hand-held forehead thermometers. An automatic infrared thermometer is shown in *Figure 14*. Passengers do not have to slow down or stop while checking temperature, they just need to walk at their normal speed, staff can find whose temperature is abnormal by looking at the computer screen.

Figure 14 – The automatic infrared thermometer installed at the metro entrance (Source: www.163.com)

Optimisation measure #3: Arrange volunteers or staff to help people unfamiliar with smartphones. People without a health QR code need to apply for one before they can enter the metro station. People unfamiliar with smartphones need a longer time (3.5 minutes is set in the original model) to apply for the code, if volunteers or staff are there to help, a lot of time can be saved. In the model with Measure #3, volunteers or staff are there to help apply for the health QR code or sign the health declaration, 1.5 minutes is set to be the time needed to apply for a health QR code or finish sign the health declaration with help. *Figure 15* shows the entering process of passengers from Entrance E with Measure #3, similar processes of passengers entering from other entrances are also established in the AnyLogic model with Measure #3.

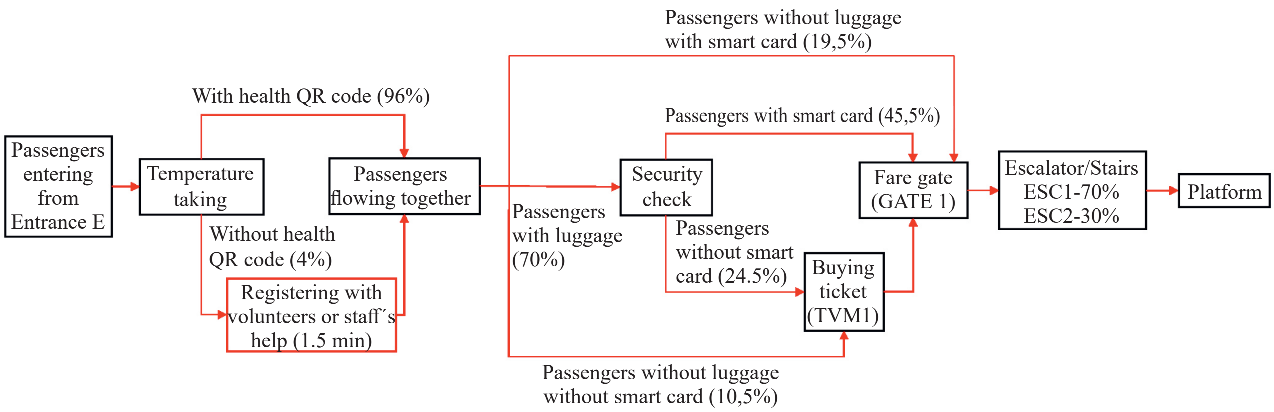

Figure 15 – The entering process of passengers from Entrance E with Measure #3

5.2 Results discussion

The calculation of the models with optimisation measures yielded valuable insights into passenger entry rates within 5 and 10 minutes. *Tables 5 and 6* present the number of passengers entering through different gate machines during these timeframes. These data provide a comprehensive overview of the impact of optimisation measures on passenger flow.

Table 5 – The number of passengers entered through different check-in gate machines in 5 minutes

Gate machine	The number of passengers entered				
	Without anti-epidemic measures	With anti-epidemic measures	With optimisation measure #1	With optimisation measure #2	With optimisation measure #3
GATE 1	53	25	22	47	25
GATE 2	65	55	45	61	54
GATE 3	26	21	28	27	15
GATE 4	57	29	28	48	27
GATE 5	68	49	52	49	55

Table 6 – The number of passengers entered through different check-in gate machines in 10 minutes

Gate machine	The number of passengers entered				
	Without anti-epidemic measures	With anti-epidemic measures	With optimisation measure #1	With optimisation measure #2	With optimisation measure #3
GATE 1	119	65	60	122	62
GATE 2	162	146	129	160	126
GATE 3	69	43	53	64	46
GATE 4	107	66	64	115	66
GATE 5	169	125	125	140	127

Here, the get-through efficiency of each gate machine with different optimisation measures is defined as follows:

$$\eta = \frac{m}{n_1} \tag{1}$$

where, m is the number of passengers entered through every check-in gate machine under the condition that an optimisation measure is taken, and n_1 is the number of passengers entered through every check-in gate machine under the condition that no anti-epidemic measure is taken. Then the get-through efficiency of each gate machine under different optimisation measures can be compared.

The get-through efficiency of each gate in 5 minutes with optimisation measures #1, #2 and #3 in place are shown in *Figure 16*. As can be seen from the figure, when optimisation measure #1 is taken, the get-through efficiency of other gates is all below 70%. When optimisation measure #3 is taken, the get-through efficiency of each gate varies between 47%~83%, and the get-through efficiency of each gate varies between 72%~104% when optimisation measure #2 is taken.

The get-through efficiency of each gate in 10 minutes under the condition that optimisation measures #1, #2 and #3 are taken are shown in *Figure 17*. As can be seen from the figure, when optimisation measures #1, #2 and #3 are taken, the get-through efficiency of each gate varies between 50%~80%, 82%~107% and 52%~78%, respectively.

The simulation results provide valuable insights into the crowd densities 10 minutes into the simulation when optimisation measures #1, #2 and #3 are implemented. *Figures 18, 19 and 20* visually illustrate these crowd densities, enabling a detailed analysis of the effectiveness of each optimisation measure.

Upon reviewing *Figure 18*, it becomes evident that when optimisation measure #1 is implemented, serious crowding occurs at Entrances B, C, D, E and H. The crowd densities at these entrances reach approximately 1.5 persons/m^2, and the waiting queues of passengers at these entry points are notably long. This suggests that optimisation measure #1 does not effectively alleviate crowding issues and may hinder passenger flow efficiency.

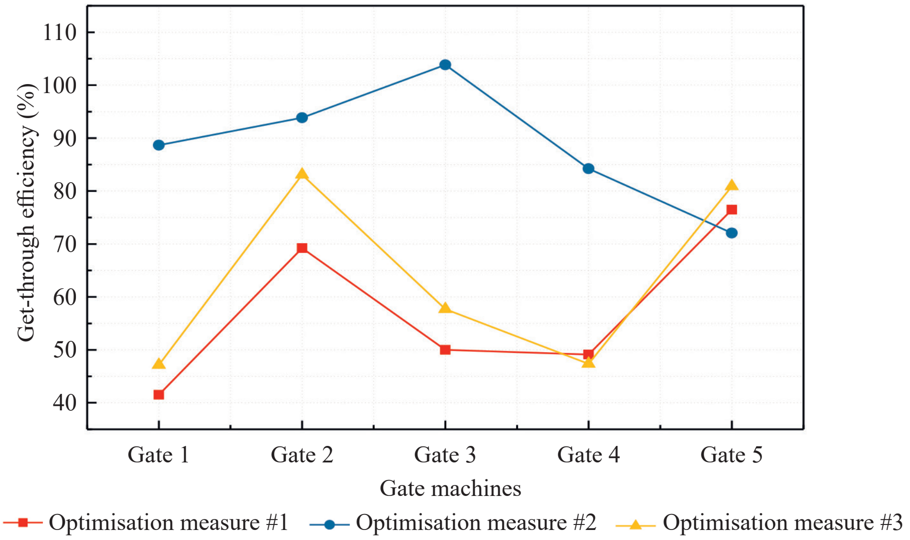

Figure 16 – Get-through efficiency of each gate in 5 minutes with different optimisation measures in place

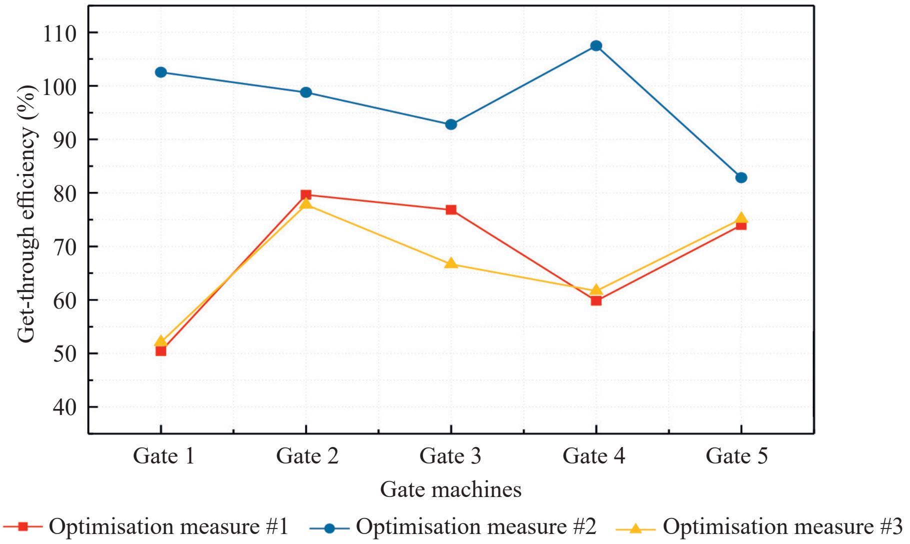

Figure 17 – Get-through efficiency of each gate in 10 minutes with different optimisation measures in place

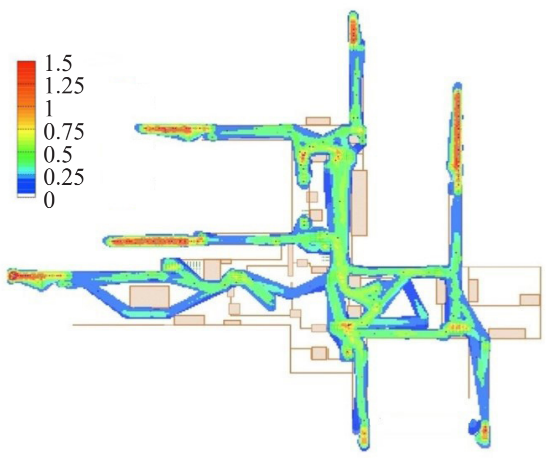

Figure 18 – The crowd density (persons/m²) at 10 minutes after the simulation begins under the condition that optimisation measure #1 is taken

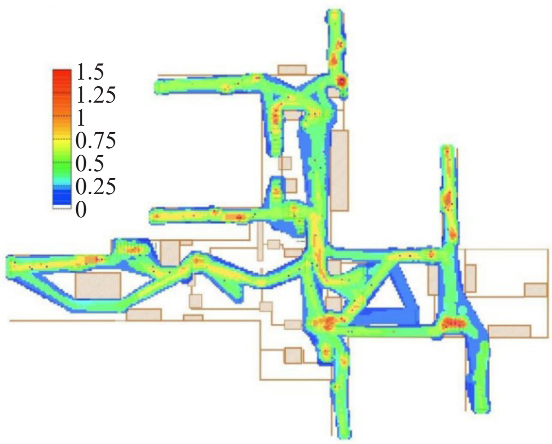

Figure 19 – The crowd density (persons/m²) at 10 minutes after the simulation begins under the condition that optimisation measure #2 is taken

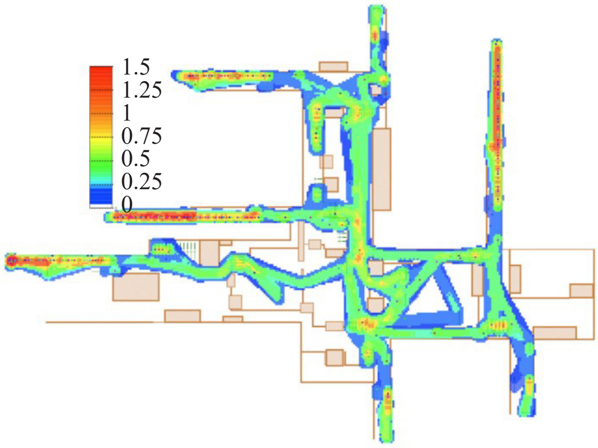

Figure 20 – The crowd density (persons/m^2) at 10 minutes after the simulation begins under the condition that optimisation measure #3 is taken

In contrast, *Figure 19* showcases the outcomes when optimisation measure #2 is adopted. It reveals a noticeable improvement, as no significant crowding is observed at any entrance. The crowd densities within most areas of the station hall and entrances remain below 1.5 persons/m^2. This indicates that optimisation measure #2 effectively manages crowd densities, resulting in a more seamless and comfortable experience for passengers.

Figure 20 showcases the outcomes when optimisation measure #3 is adopted. When optimisation measure #3 is taken, serious crowds of passengers will appear at Entrances C, D and H as shown in *Figure 20*. The waiting queue of passengers at Entrance H is longer than 25 m.

After careful analysis, it has been observed that optimisation measure #2, which involves utilising an automatic infrared thermometer to measure passengers' temperature rather than using handheld forehead thermometers, exhibits the highest efficiency in terms of passenger throughput at each entrance gate. Moreover, when compared to optimisation measures #1 and #3, this approach significantly reduces the occurrence of crowding at the entrance points.

6. CONCLUSIONS

During the COVID-19 pandemic, metro stations in Guangzhou implemented various anti-epidemic measures to ensure the safety of passengers. The two most widely used measures, health condition registration and temperature checks were evaluated for their impact on inbound passenger flow. Simulation models based on the T station of Guangzhou Metro were utilised to assess the effects of three different optimisation measures. The findings of this study are summarised below.

Firstly, the implementation of health condition registration and temperature checks resulted in a significant decrease in the number of passengers entering the T metro station within certain periods of time. Within time spans of 0-5minutes and 0-10minutes, the reduction ranged from 15% to 53% and 10% to 45%, respectively. This indicates that these anti-epidemic measures have a substantial impact on the efficiency of inbound passenger flow.

Secondly, the study examined three optimisation measures and their effects on the efficiency of the gate machines. The measures included increasing the distance between security and health checks, as well as deploying volunteers or staff to assist individuals who don't have health QR codes. However, it was observed that these optimisation measures did not have a noticeable effect on the efficiency of the gate machines. Therefore, alternative approaches might be necessary to improve the flow of passengers through these checkpoints.

Lastly, the study explored the use of automatic infrared thermometers as an alternative to hand-held forehead thermometers for temperature checks. The results indicated that the implementation of automatic infrared thermometers had a positive impact on the efficiency of each entrance gate. Within a 10-minute timeframe, the get-through efficiency of each gate increased by 82% to 107%. Moreover, the introduction of automatic infrared thermometers significantly alleviated crowding at the entrances and in the station hall. This suggests that the use of advanced technology can greatly improve the overall efficiency and safety of the metro station during the pandemic.

In conclusion, the evaluation of anti-epidemic measures in Guangzhou's metro stations revealed important insights. The implementation of health condition registration and temperature checks had a significant impact on the efficiency of passenger flow. However, certain optimisation measures, such as increasing distance and assisting smartphone-unfamiliar individuals, did not yield notable improvements. On the other hand, the use of automatic infrared thermometers proved to be highly effective in enhancing gate efficiency and reducing crowding. These findings can serve as valuable guidelines for the implementation of anti-epidemic measures in metro stations to ensure the safety and well-being of passengers during similar health crises.

7. LIMITATIONS AND FUTURE WORKS

The major limitation of this research is that the effectiveness of optimisation measures is studied by simulation only. If the anti-epidemic measures are no longer implemented, it is difficult to evaluate the effectiveness of the measures based on field investigation. In the next stage, cooperation with metro stations is planned to be carried out, and the effectiveness of more crowd mitigation and passenger flow management measures will be studied to improve the safety operation ability of metro stations under the conditions of a similar epidemic.

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REFERENCES

[1] Gkiotsalitis K, Cats O. Optimal frequency setting of metro services in the age of COVID-19 distancing measures. *Transportmetrica A: Transport Science*. 2020;105–118. DOI: 10.13140/RG.2.2.35560.70406.

[2] Hu J, Ling C, Wang J. Analysis and suggestion on COVID-19 impact on subway operation. *Modern Urban Transit*. 2020;2020(7):109–114. Chinese.

[3] Park J. Changes in subway ridership in response to COVID-19 in Seoul, South Korea: Implications for social distancing. *Cureus*. 2020;12(4):e7668. DOI: 10.7759/cureus.7668.

[4] Shirai Reyna OS, Flores de la Mota I, Rodríguez Vázquez K. Complex networks analysis: Mexico's City metro system during the pandemic of COVID-19. *Case Studies on Transport Policy*. 2021;9(4):1459–1466. DOI: 10.1016/j.cstp.2021.07.003.

[5] Shenzhen Government Online. *Some metro stations closed due to COVID-19 control*. http://www.sz.gov.cn/en_szgov/news/photos/content/post_9588952.html [Accessed 14th Dec. 2022].

[6] Bruinen de Bruin Y, et al. Initial impacts of global risk mitigation measures taken during the combatting of the COVID-19 pandemic. *Safety Science*. 2020;128:104773. DOI: 10.1016/j.ssci.2020.104773.

[7] Wang D, et al. Mobility in post-pandemic economic reopening under social distancing guidelines: Congestion, emissions, and contact exposure in public transit. *Transportation Research Part A: Policy and Practice*. 2021;153:151–170. DOI: 10.1016/j.tra.2021.09.005.

[8] Gostic K, et al. Estimated effectiveness of symptom and risk screening to prevent the spread of COVID-19. *eLife*. 2020;9:e55570. DOI: 10.7554/eLife.55570.

[9] Quilty B, Clifford S, Flasche S, Eggo R. Effectiveness of airport screening at detecting travellers infected with novel coronavirus (2019-NCoV). *Eurosurveillance*. 2020;25(5). DOI:10.2807/1560-7917.ES.2020.25.5.2000080.

[10] Dong S, Chen F, Ding W, Zhou J. Prevention and control of COVID-19 in subway stations: An optimization strategy for placing location QR codes. *Tunnelling and Underground Space Technology*. 2022;2022(127):104615.

[11] Hirschhorn F. A multi-level governance response to the Covid-19 crisis in public transport. *Transport Policy*. 2021;112:13–21. DOI: 16/j.tranpol.2021.08.007.

[12] Violato C, Violato EM, Violato EM. Impact of the stringency of lockdown measures on Covid-19: A theoretical model of a pandemic. *PLOS ONE*. 2021;16(10):e0258205. DOI: 10.1371/journal.pone.0258205.

[13] Zhong L, Diagne M, Wang W, Gao J. Country distancing increase reveals the effectiveness of travel restrictions in stopping COVID-19 transmission. *Commun Phys*. 2021;4(1):1–12. DOI: 10.1038/s42005-021-00620-5.

[14] Thompson K, Schofield P. An investigation of the relationship between public transport performance and destination satisfaction. *Journal of Transport Geography*. 2007;15(2):136–144. DOI: 10.1016/j.jtrangeo.2006.11.004.

[15] Irtema HIM, et al. Case study of the behavioural intentions of public transportation passengers in Kuala Lumpur. *Case Studies on Transport Policy*. 2018;6(4):462–474. DOI: 10.1016/j.cstp.2018.05.007.

[16] Jenelius E, Cebecauer M. Impacts of COVID-19 on public transport ridership in Sweden: Analysis of ticket validations, sales and passenger counts. *Transportation Research Interdisciplinary Perspectives*. 2020;8:100242. DOI: 10.1016/j.trip.2020.100242.

[17] Chang H-H, Lee B, Yang F-A, Liou Y-Y. Does COVID-19 affect metro use in Taipei? *Journal of Transport Geography*. 2021;91:102954. DOI: 10.1016/j.jtrangeo.2021.102954.

[18] *Air travel down 60 percent, as airline industry losses top $370 billion: ICAO | UN News*. https://news.un.org/en/story/2021/01/1082302 [Accessed 15th June 2023].

[19] Auad R, et al. Resiliency of on-demand multimodal transit systems during a pandemic. *Transportation Research Part C: Emerging Technologies.* 2021;133:103418. DOI: 10.1016/j.trc.2021.103418.

[20] Chen L, et al. Prevention and control of micro crowd infection in subway station based on social force model. *Chin. J. Infection Control*. 2022;21:22–29.

[21] Zhang N, Shi T, Zhong H, Guo Y. COVID-19 prevention and control public health strategies in Shanghai, China. *Journal of Public Health Management and Practice.* 2020;26(4):334. DOI: 10.1097/PHH.0000000000001202.

[22] Betsch C, et al. Social and behavioral consequences of mask policies during the COVID-19 pandemic. *Proceedings of the National Academy of Sciences.* 2020;117(36):21851–21853. DOI: 10.1073/pnas.2011674117.

[23] Abushamleh H, Al-Hiyari N, Qusef A. The intention to use e-wallet during Covid-19 pandemic in developing country. *2021 12th International Conference on Information and Communication Systems (ICICS)*. 2021. p. 310–316. DOI: 10.1109/ICICS52457.2021.9464554.

[24] Basnak P, Giesen R, Muñoz JC. Estimation of crowding factors for public transport during the COVID-19 pandemic in Santiago, Chile. *Transportation Research Part A: Policy and Practice.* 2022;159:140–156. DOI: 10.1016/j.tra.2022.03.011.

[25] Gkiotsalitis K, Cats O. Public transport planning adaption under the COVID-19 pandemic crisis: Literature review of research needs and directions. *Transport Reviews.* 2021;41(3):374–392. DOI: 10.1080/01441647.2020.1857886.

[26] Choi M, Ku D, Jeong H, Lee S. A face mask wearing detection technique to protect against Coronavirus in metro stations. *Proceedings of the Institution of Civil Engineers - Municipal Engineer* 2023. p. 1–11. DOI: 10.1680/jmuen.22.00037.

[27] Farman H, et al. Real-time face mask detection to ensure COVID-19 precautionary measures in the developing countries. *Applied Sciences.* 2022;12(8):3879. DOI: 10.3390/app12083879.

[28] Lee J, Marinov M. Analysis of rail passenger flow in a rail station concourse prior to and during the COVID-19 pandemic using event-based simulation models and scenarios. *Urban Rail Transit.* 2022;8(2):99–120. DOI: 10.1007/s40864-022-00167-w.

[29] Bilde BA, Andersen ML, Harrod S. Social distance modeling on the Copenhagen, Denmark, metro. *Journal of Transportation Engineering, Part A: Systems.* 2022;148(2):04021105. DOI: 10.1061/JTEPBS.0000633.

[30] Lu Y, et al. Simulation analysis of passengers' rescheduling strategies in metro station under COVID-19. *Tunnelling and Underground Space Technology.* 2023;134:105023. DOI: 10.1016/j.tust.2023.105023.

[31] Siewwuttanagul S, Kamkliang S, Prapaporn W. Investigation on physical distancing measures for COVID-19 mitigation of rail operation in Bangkok, Thailand. *International Journal of Building, Urban, Interior and Landscape Technology (BUILT).* 2020;15:93–102.

[32] Ha J, Jo S, Nam H, Cho S. The unequal effects of social distancing policy on subway ridership during the COVID-19 pandemic in Seoul, South Korea. *J Urban Health.* 2022;99(1):77–81. DOI: 10.1007/s11524-021-00585-4.

[33] Kamga C, et al. An estimation of the effects of social distancing measures on transit vehicle capacity and operations. *Transportation Research Interdisciplinary Perspectives.* 2021;10:100398. DOI: 10.1016/j.trip.2021.100398.

[34] Mokshin VV, Kirpichnikov AP, Soiko AI. Simulation and optimization of the cargo terminal in the AnyLogic environment. *J. Phys.: Conf. Ser.* 2019;1368(4):042082. DOI: 10.1088/1742-6596/1368/4/042082.

[35] Yakimov IM, Trusfus MV, Mokshin VV, Kirpichnikov AP. AnyLogic, ExtendSim and Simulink overview comparison of structural and simulation modelling systems. *2018 3rd Russian-Pacific Conference on Computer Technology and Applications (RPC)*. 2018. p. 1–5. DOI: 10.1109/RPC.2018.8482152.

[36] Li X, Khattak AJ, Kohls AG. *Signal phase timing impact on traffic delay and queue length – A intersection case study*. IEEE; 2016. p. 3722–3726.

[37] Dukulis I, Birzietis G, Kanaska D. Optimization models for biofuel logistic systems. *Engineering for Rural Development*. 2008;05:283–289.

[38] Nassar K, Ahmed B. A simulation study of the effect of mosque design on egress times. *Proceedings of the 2012 Winter Simulation Conference (WSC)*. IEEE; 2012. p. 1–8. DOI: 10.1109/WSC.2012.6465153.

[39] Liao Y, Liao G, Lo S. Influencing factor analysis of ultra-tall building elevator evacuation. *Procedia Engineering.* 2014;71:583–590. DOI: 10.1016/j.proeng.2014.04.083.

[40] *AnyLogic Help*. https://anylogic.help/ [Accessed 29th Nov. 2022].

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新冠疫情期间地铁健康登记和体温检查对进站客流的影响及优化措施研究

摘要：

广州地铁在新冠疫情期间实施了健康登记和体温检查，以遏制病毒的传播。然而，上述措施的实施可能会影响进站客流通过效率，并增加车站入口及站厅的拥挤程度。为对此类问题进入深入分析，利用AnyLogic开发了基于T地铁车站的客流仿真

模型。基于模型计算结果，比较了采取防疫措施和不采取防疫措施两种条件下进站客流的通行效率，同时对实施防疫措施后出入口和车站大厅内的拥挤问题进行了分析。结果显示，实施防疫措施后，5分钟内成功通过检票机的旅客数量减少15%~53%，10分钟内减少10%~45%。此外，模拟结果还显示一些入口出现非常拥挤的现象。为找到提高通过效率和缓解拥挤的有效优化措施，还模拟分析了增加安检和健康检查之间的距离、使用自动红外温度计、安排志愿者或工作人员协助登记等三项措施的有效性。结果显示，使用自动红外线测温仪取代手持式额头测温仪，可有效提高进站乘客通过效率并纾缓车站入口及站厅内的拥挤问题。

关键字：
体温检查；健康登记；地铁车站；新冠肺炎；客流；安全；优化措施.