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The Prediction of Evacuation Efficiency on Metro Platforms Based on Passengers' Decision-Making Capability

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Abstract: In the research, decision-making capabilities are explored in relation to the prediction of evacuation efficiency to improve forecast accuracy on metro platforms. For this purpose, this study reviewed theories related to evacuation behaviours utilising the anomaly-seeking approach and the paradigm of relationship development. The conceptual framework of decision-making capability and evacuation behaviours was explored based on risk perception, level of emergency knowledge, survivability and emotion, and their relationship with the partial least squares equation was constructed. A predictive model of evacuation efficiency and its differential equations incorporating this relationship were also proposed based on the epidemic model. By developing and testing the conceptual framework and model, theoretical support is provided for evacuation behaviour, while assisting emergency management in developing plans and measures to respond to emergencies on metro platforms. This study realises the possibility of predicting evacuation efficiency from a decision-making capability perspective.

Keywords: decision-making capability; evacuation behaviours; metro evacuation; evacuation efficiency; prediction

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1. Introduction

The metro has become one of the primary modes of transportation for inhabitants, significantly reducing rising pollution and traffic congestion [1,2]; however, metro stations are also experiencing increased passenger traffic and have grown overcrowded [3]. Furthermore, the underground form of metro stations makes them prone to crises [4] and a severe safety threat [5]. Previous relevant catastrophic incidents have proven that irrational or temporary evacuation strategies are the root cause of disasters arising from emergency management failures [6]. Therefore, evacuation efficiency, as one of the important indicators in the evaluation of metro safety performance, has been the focus of attention in the field of transportation [6,7].

The evaluation of evacuation efficiency has been studied from both the macro and micro perspectives. Macroscopic evacuation models view the crowd as a continuous and flowing fluid [8], with the crowd density and overall flow speed as evaluation indicators [9]. Nevertheless, they ignore people's interactions and behaviours. Microscopic evacuation models focus more on the speed differences of individuals in a crowd and the effects of their behaviours [10–12]. In addition, based on the micro-analytical perspective of evacuation efficiency, the spatial characteristics of the environment are also considered to be an important aspect that would have an impact on evacuation behaviours [13]. The effect of velocity on specific evacuations caused by flood depth is presented by experiments on different individuals in the static water [14]. It suggests that the level of damage to the environment is thought to affect the efficiency of pedestrian evacuation. Additionally, the spatial features also interact with the perception of pedestrians [15], which in turn can have an impact on the pathfinding behaviour [16]. However, it falls short in expressing the influence of individual capabilities on behaviours and behavioural interactions in the crowd [17,18]. As unexpected disasters are extremely complex and often associated with extreme consequences [19], it is difficult to effectively predict and assess evacuation efficiency without a sufficient understanding of the causes that generate behavioural strategies [20]. Based on this viewpoint, research on evacuation has delved from the initial simulation of behavioural rules to the influence of psychological characteristics on behavioural strategies. Given the impact that emotions can have on decision making, emotions during an evacuation should be considered [21] to make the simulation of behaviour in evacuation more realistic [22]. Based on this, personality characteristics were also included in studies to model their influence of them on decision making during evacuation [23,24]. Considering the influence of social roles, herd behaviour has also been considered to simulate the evacuation of groups with different social structures [25] and is thought to potentially affect responses to evacuation, creating mutual help or competition between groups [26], suggesting that the choice of behavioural approach during evacuation is related to many factors such as risk perception and the stock of emergency knowledge [27,28]. As it is influenced by multiple factors, a systematic analysis of the mechanism that generates the behavioural strategic tendencies of pedestrians during evacuation is necessary [29], which is essential for the development of robust evacuation plans and procedures in public places [30].

Notwithstanding, there have been considerable studies that have considered post-disaster evacuation behaviours in terms of investigations or specific behavioural rules suggesting that decision-making capabilities have an impact on behaviour. It seems to have been ignored that the incorporation of individual decision-making capabilities in the prediction of evacuation efficiency explains evacuation behaviours. Decision-making capability is defined as the tendency of an individual to follow normative principles in the decision-making process [31], which typically involves the influence of aspects such as emotion, cognition and memory related to the performance of perceptual skills on problem-solving ability [32]. Decision-making capability is critical for components of environmental adaptation [28,33] since it is relevant to performance at work and in life [34]. Therefore, the decision-making capability is an important aspect in exploring the generation of evacuation behaviours [35], which needs to be taken into account [36]. It is still difficult to pinpoint the decision-making capability that affects evacuation behaviours [37]. Without taking into account the important components of decision-making capability, it may, however, lead to less accurate predictions of evacuation behaviours and efficiency [17]. Considering that decision-making capability is highly correlated with evacuation behavioural tendencies, systematic and procedural identification of the relationship between decision-making capability and evacuation strategy behavioural tendencies is necessary. Therefore, this study attempts to identify various indicators to measure individual decision-making capability in an evacuation, and determine the relationship between decision-making capability and evacuation behavioural strategies to reveal how decision-making capability acts on different evacuation behavioural strategies. Additionally, this study aims to develop a predictive model for evacuation efficiency to enhance the prediction of metro evacuation efficiency.

2. Conceptual Framework Building

2.1. Integrating Decision-Making Capacity in Evacuation Behavioural Strategy Based on Literature

As revealed in the previous section, knowledge gaps in the field of evacuation efficiency prediction suggested that existing theories cannot provide correct predictions for specific evacuation phenomena for which researchers have been ambiguous [38]. It indicates that established theories may be replaced by broader and more accurate theories of prediction [39]. This section, therefore, proposes a conceptual framework for evacuation behavioural strategies to bridge the gap in existing assessments of evacuation efficiency that lack integrated decision-making capabilities. The conceptual framework of this study integrates risk perception capabilities, survival capabilities, emotions, and level of emergency knowledge. To incorporate these factors into decision-making capabilities, this study utilises a cross-disciplinary research approach that combines the anomaly-seeking approach and the paradigm of relational development systems. The anomaly-seeking approach which applies to exceptions to established general principles promotes a re-examination of the general principle or theory [39]. The paradigm of relational development, on the other hand, is a complementary process in the construction and acquisition of knowledge, which explains the discovery of anomalies in the old paradigm as well as the emergence of discoveries. It is also a perspective for the development of behavioural, cognitive and affective sciences [40]. A theory of concepts is a collection of multiple related propositions and a result of the intertwined evolution of people's knowledge of things and themselves [40]. It is constructed to establish a balance between induction, deductive reasoning and research [41]. It is, therefore, feasible to build the conceptual framework for this study utilising both research methods. Based on this, the theoretical construction of this study utilises the anomaly-seeking approach to retrace the widespread phenomena in evacuation behaviours in conjunction with the paradigm of the relational developmental system. Knowledge gaps in previous research are then bridged by examining phenomena within phenomena and other disciplinary perspectives [42]. This framework forms the basis of this study.

2.2. Understanding Evacuation Behaviours Based on the Anomaly-Seeking Approach and the Relational Developmental System Paradigm

Real evacuation cases in the past have shown that evacuation does not always succeed even when there are no obstacles in terms of physical health and space for escape routes [38]. It has led scholars to focus on the psychological and social aspects of relationships. Retracing the widespread phenomenon of evacuation reveals that people may be under great stress in the face of emergencies, which leads to a general loss of self-control and decision making that produces non-social and irrational behaviour [43,44]. However, while people do respond emotionally and make different behavioural decisions in response to stress [45], evacuees behave more socially than in mass panic [46,47] and tend to make rational decisions and display pro-social behavioural decisions rather than lose self-control [48]. During the evacuation, depending on their social identity, people make a range of behaviours that conform to social norms [46,49] and decisions that are consistent with group behavioural tendencies [50]. Additionally, such decision making may be associated with sustainable or unsustainable behaviours [51]. However, in evacuated groups, in contrast to irrational conflict, the expression of mutual behavioural strategies tends to dominate [52].

To further understand evacuation behaviours, there is a review of the "phenomena within phenomena" of evacuation behaviours. In general, evacuation behaviours are divided into pre-evacuation behaviours and behaviours during evacuation. At the beginning of emergencies, there is a great deal of uncertainty in individual decision making due to limited information. Such uncertainties may lead individuals to gather information to verify warnings from those around them or public announcements and to assess the severity of the incident or evacuate immediately [53,54]. Some passengers also choose the passive strategy of trusting the guidance and assistance of the relevant authorities and waiting for help or directions for actions in a safe location [55], whereas during the evacuation, crowds form groups with the same behavioural norms due to social identity [56]. Additionally, in emergencies, as people usually determine what is right by finding out what others think is right, this makes people more inclined to give up their abilities and transfer control over themselves to others, in turn generating herd behaviour [57]. Under the influence of such socialisation phenomena, people tend to exhibit cooperative strategic behaviours of subordination or helping others [53]. In addition, while the assumptions of panic theory have been shown not to apply, in emergencies, people may also develop competing behavioural strategies such as trying to outrun others to escape early or being reluctant to help those around them in need [53], which can easily lead to fatal consequences such as stampedes [58].

A further review of the strategies of evacuation behaviour through the lens of other disciplines reveals that researchers have now focused on sociology, psychology, risk management and many other disciplines to explain evacuation behaviours [20]. As emergencies are often perceived as actual or anticipated threats and disruptions to the steady state of the organism, it is proposed that the decision-making capability in such situations is highly correlated with the cognitive ability [59]. Cognitive processes are considered necessary to generate behavioural decisions according to prevailing cognitive science. It works in conjunction with psychological or mental mechanisms in behaviour [60] and is a behavioural constraint [61] and interpretation [51] that needs to be considered in emergency management. As individuals perceive cues during emergencies, they interpret them and assess the situation to determine the behaviours to be taken [62]. However, emotions also encompass a person's positive and negative reactions to events [63], which can influence behavioural decisions [64]. Analysis through post-disaster surveys has all shown that individuals may experience varying degrees of negative emotions during evacuation [65], accompanied by behaviours such as overwhelm, information seeking and shelter seeking [45]. This suggests that it is necessary to consider cognition and emotion when making predictions about evacuation behaviours [66]. In addition, the influence of personality on behavioural decision making has also been considered, which alongside emotions has been used to analyse the impact on behaviour to guide evacuation [23]. However, it did not seem to help to improve the simulation of evacuation situations [67]. In addition, numerous relevant evacuation studies have examined the influence of risk perception and familiarity with the space on evacuation behaviours, although a higher sense of security provided by the environment may cause more delay in evacuation initiation [30,68,69]. However, it is generally accepted that the greater the stock of emergency knowledge, the more rational the evacuation process is likely to be. As evacuation behavioural strategies have been studied, their influencing factors have been extracted in various research areas. This suggests that it is necessary to focus on and integrate the components that influence evacuation behaviours as proposed by these different studies within different fields to better predict evacuation behaviours.

2.3. Conceptual Framework

Utilizing the paradigm of relationship development and the anomaly-seeking approach, this study has elaborated on the various influencing factors through a systematic literature review to integrate the conceptual framework of decision-making capability and strategies of evacuation behaviours. As individuals with high-risk perceptions are more inclined to affirm the severity of the contingency and positively influence the choice of evacuation behaviour strategies [70]. Thus, responses to cues are derived from the aspect of risk perception. In terms of emotions, although the panic theory is inapplicable to the study of behavioural choice nowadays. However, to a certain extent, emotional responses in evacuation also reveal the relationship between emotions and behavioural choices [45]. Thus, the emotional response to receiving emergency cues and the emotions in the face of a crowd both originate from the emotional aspect. As an extension of cognitive abilities, the safety knowledge aspect contributes to people's familiarity with emergency safety facilities. In addition, we used the eight survivability factors already proposed as an extension of personality variables [71]. This includes a leadership factor with the habit of gathering and organising people, a problem-solving factor with good strategic problem solving, an altruistic factor with the ability to care for and help others, a stubborn personality with the ability to stick to one's attitudes or habits, a habit of conforming daily behaviour to social norms of etiquette, the ability to maintain calm emotional regulation in stressful situations, self-transcendence with a sense of responsibility to society and positive behavioural aspects of maintaining or improving oneself in everyday life [71]. Consequently, various sources were used in this study to construct measures of evacuation behavioural strategies, as shown in Table 1. The framework which consists of a level of emergency knowledge, risk perception, emotion of response, and survivability was developed to explain evacuation behavioural strategies. Figure 1 illustrates the main structure of the conceptual framework for bridging the knowledge gap in current evacuation behaviours research. As the evacuation efficiency of a crowd can be significantly influenced by the evacuation behaviours of individuals in the group [72], evacuation behaviours are influenced by decision making [28]. Considering this, it is assumed that "risk perception, emotion, survivability and knowledge of emergency response have an impact on evacuation efficiency", and that the components of decision-making capability have an impact on evacuation behaviours at the metro platform. Figure 2 demonstrates the structural model of the impact of the components of decision-making capability on evacuation behaviours.

Table 1. Construction of predictive indicators for evacuation behaviour strategies.

Construct	Indicators	Reference Models and Modified from
The capability of risk perception(CPRP)	CPRP_1: the feeling of hearing the alarm; CPRP_2: smelling something burning; CPRP_3: informed by others; CPRP_4: seeing the accident happened	E-research of the initial feelings about administration building fire, E-Survey of psychologies and behaviours of the metro [55,73];
Level of emergency knowledge (LEGK)	LEGK_1: Evacuation education/experience; LEGK_2: Level of familiarity with exit position; LEGK_3: Level of familiarity with emergency button position and the use of the subway transportation station platform; LEGK_4: Level of familiarity with the emergency evacuation passageway of the subway transportation station; LEGK_5: the location/position of the subway transportation fire extinguisher and with its use	E-Survey of psychologies and behaviours of the metro, C-protective action model, C- Protective Action Decision Model (PADM), C-the survey of passengers' awareness and perceptions of wayfinding tools [45,69];
Response in Emotion (RPEM)	RPEM_1: confronted with heavy crowd flows; RPEM_2: during an emergency event	E-Emotional response, E- "social attachment" model; E-X-machines, E-Survey of psychologies and behaviours of the metro, E-BeSeCu-S—a self-report instrument for emergency survivors crowds [23,45,52,74–76]
Individual Viability (INVB)	INVB_1: leadership; INVB_2: problem-solving; INVB_3: altruism; INVB_4: stubbrornness; INVB_5: etiquette; INVB_6: emotion regulation; INVB_7: self-transcendence; INVB_8: active well-being	P-OCEAN model, P-research in terms of personality factors and support types, C-Measuring human perceptions of developing room fires, P-Relationship between Emergency Escape Capability and DISC Personality Type [71,77,78].

Note: Reference model of constructs are denoted by C = cognitive ability; P = personality traits; and E = emotion theory.

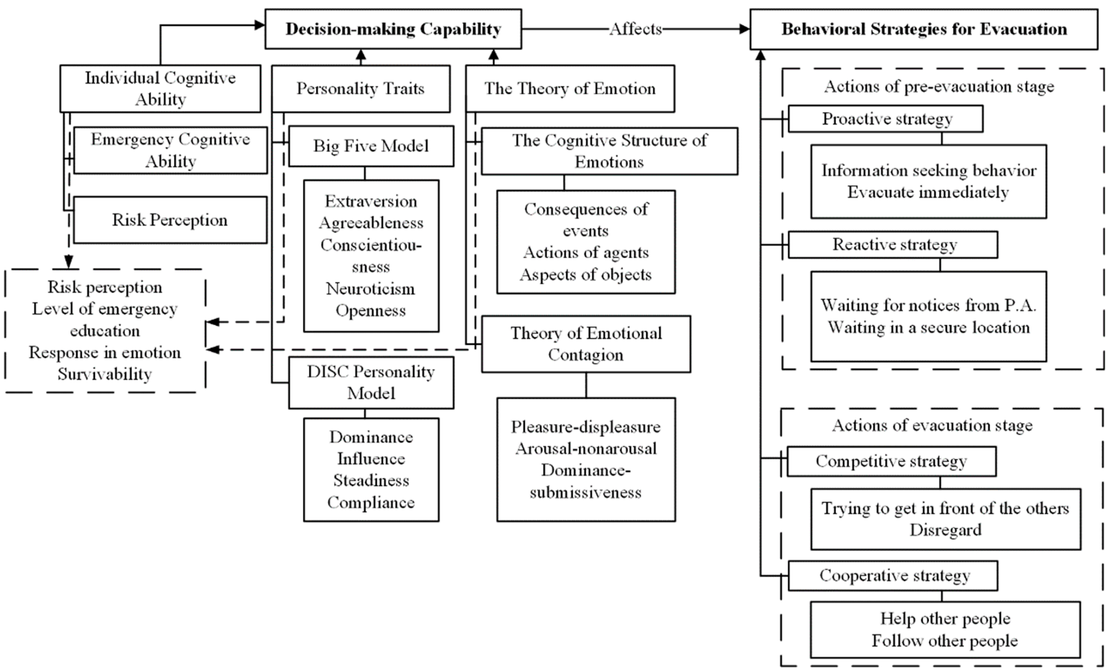

Figure 1. Components of the conceptual framework.

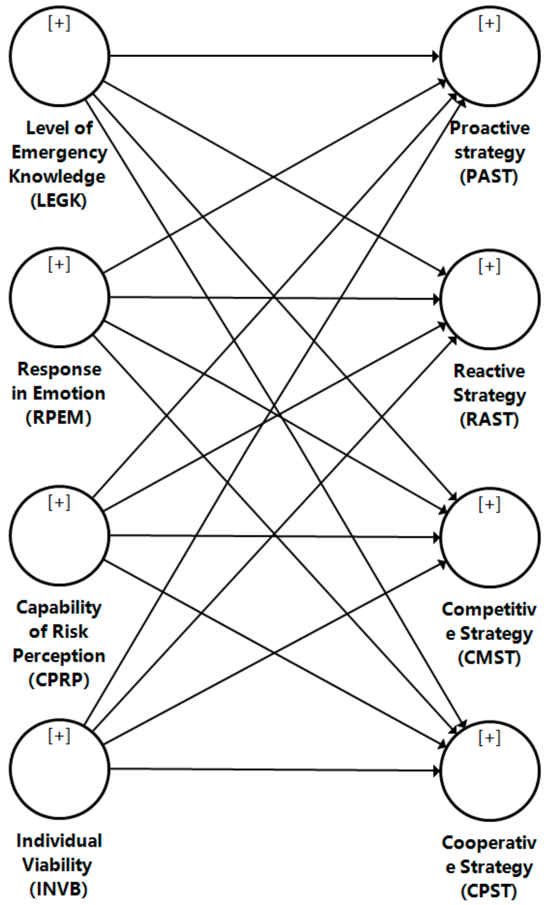

Figure 2. Hypothetical structural model.

3. Research Method and Procedures

The in-depth literature review provided the theoretical basis for this research in designing the conceptual framework, empirical analysis and development of the model. In this study, questionnaires were distributed in the four interchange platforms of the Harbin metro in order to discuss the relationship between decision-making capability and evacuation behavioural strategies. Harbin's Metro is an important underground rail transit in the city, with four interchange stations and an average daily passenger volume of approximately more than two hundred thousand. The questionnaires were distributed to passengers on site, collected after completion and distributed to passengers in the actual underground stations, and the data collected was statistically analysed. The design of the questionnaire consisted of three parts. Part A solicited general information about the respondents including age, occupation, frequency of underground travel, and education. Part B included a survey of the respondents' survivability, knowledge of emergency response, risk perception, and emotions. This section of the survey allows passengers to make a realistic assessment of the various indicators of decision-making capability and to reflect individual performance in the various aspects of decision-making capability in numerical form. This provides a basis for calculating the impact of the components of decision-making capability on evacuation behaviours. Additionally, Part C included a survey of evacuation behavioural tendencies. This section investigates the behavioural strategy tendencies of passengers before and during the evacuation process. The results of this section reflect the evacuation strategy tendencies of passengers by the magnitude of the score. To capture the above characteristics and behavioural tendencies of individuals except for the emotional part, a 5-point Likert scale was used, with 1 representing strongly disagree, 2 representing disagree, 3 representing neutral/fair, 4 representing agree and 5 representing strongly agree.

A total of 750 questionnaires were distributed and 680 were returned. As the behavioural tendency survey in this study is not post-disaster research, some respondents were found to have the same tendency towards different behavioural strategies during the research, therefore invalid questionnaires without obvious behavioural strategy tendencies were excluded and a total of 638 valid questionnaires were returned, with a valid return rate of 91.14% that is sufficient for analysis. In this study, to explain the tendency to sparse behavioural strategies, behavioural tendencies can be measured by their corresponding observational variables, which are referred to as measurement items or indicators. Table 2 shows the demographics of the respondents, of which 47.2% were male and 52.8% were female. The respondents were distributed across all age groups, covered all occupations and all travelled the metro with varying frequency each week. As such, they were all qualified respondents and were able to provide reasonable judgements on the propensity for evacuation behavioural strategies.

Table 2. Surveyed demographics.

Description	Frequency	Percentage (%)
	Gender	
Male	301	47.2
Female	337	52.8
	Age	
Under 20 years old	29	4.5
21–30 years old	380	59.6
31–40 years old	117	18.4
41–50 years old	83	13
Over 51 years old	29	4.5
	Weekly frequency of underground travel	
1 time	119	18.7
2 times	145	22.7
3 times	221	34.6
4 times and above	153	24
	Education	
Senior Secondary and below	107	16.8
Bachelor/Specialist degree	449	70.4
Postgraduate degree	82	12.9
	Occupation	
Individual Businesses	70	11
Corporate employees	134	21
Public Servants/Career Staff	202	31.7
No fixed occupation/retired	46	7.2
Student	186	29.2

4. Data Interpretation and Analysis

To explain the relationship between the components of decision-making capability and evacuation behaviours, this study analysed the data utilising SPSS 25.0 and SmartPLS 3.3. SmartPLS is an excellent tool for prospective predictive modelling. This study was able to develop valid empirical measures of the relationship between indicators and evacuation behaviours, providing explanations and theoretical predictions [79].

4.1. Specifying the Structural Model

The complete structural model is made up of a measurement model and a prediction model, illustrating the relationship between the research hypothesis and the evacuation behaviour strategy. As shown in the conceptual framework in Figure 1, the measurement model of this structural model consists of emergency knowledge level, emotional response, risk perception capability and survivability. The predictive model section consists of four behavioural strategies of pre-evacuation and on-evacuation. Figure 2 shows the relationship between the models, which represent the structural model for the PLS-SEM analysis of this study.

4.2. Data Analysis and Model Estimation

The questionnaire data were imported into SPSS 25.0 for reliability analysis, which showed a KMO value of 0.954 and a Cronbach's alpha value of 0.916. This indicates that the results of the questionnaire in this study are well suited for factor analysis. The indicator data was exported to SmartPLS 3.3 to estimate the model via the PLS algorithm. Figure 3 shows the R^2 values for the external loads, path coefficients and endogenous variables of the determined structural model. In terms of emotional response, for example, the external loadings for the emotional indicators are 0.628 (emotions in the face of crowds) and 0.467 (emotions in the face of unexpected events). The path coefficients then reveal the magnitude of the effect of the measurement model on the prediction model. In the case of competitive strategy, for example, contingency knowledge understanding (0.379) had the greatest influence, followed by emotion (0.340) and survivability (0.172). Finally, the R^2 value for competitive strategy was 0.709, which indicates that the three constructs above together explained 70.9% of competitive strategy.

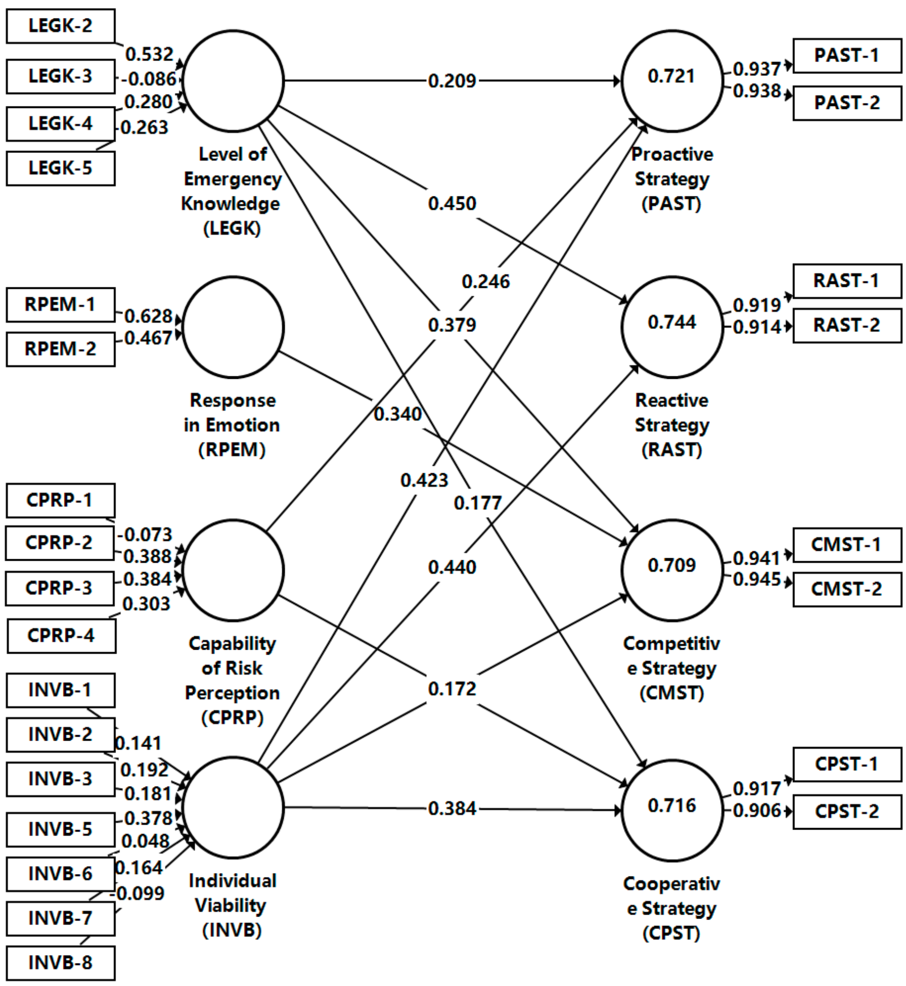

Figure 3. Final PLS structural equation model.

4.3. Assessing the Structural Model

The structural equation model for this study is made up of a predictive model for four exogenous latent variables and a reflective model for four endogenous latent variables before and during evacuation. To determine the validity and reliability of the model, we need to test the model. The process of testing predictive models involves four recognized criteria, including internal consistency, indicator reliability, convergent validity and discriminant validity [80]. First, the model is tested for internal consistency. The composite reliability values for the endogenous latent variables for the four reflective structures were

0.936 (PAST), 0.913 (RAST), 0.908 (CPST), and 0.941 (CMST), all of which were above the internal consistency requirement of 0.7. External loads over 0.708 are acceptable for the predictive model; thus, external loads are acceptable for all endogenous variables in this study. This indicates that the reliability of the indicators of the prediction model of this study has reached a satisfactory level. Secondly, the convergent validity of the model was reviewed. The assessment of the convergent validity of this model was based on the average variance extracted (AVE) values, which were 0.879 (PAST), 0.840 (RAST), 0.889 (CMST) and 0.831 (CPST) for the four behavioural strategies, all of which were above the recommended threshold of 0.5 [80]. It is suggested that measurements of the four reflective structures of the predictive model show an extremely high level of convergent validity. Finally, the Fornell–Larcker criterion was used to assess the discriminant validity of the model. Table 3 shows the results of the assessment of the Fornell–Larcker criteria. The differential validity of the proactive, cooperative, competitive and passive strategies in the prediction model was 0.938, 0.911, 0.943 and 0.916, respectively. The square roots of the means of these discriminant validities are greater than the correlations of the other latent variables, indicating that the model has satisfactory discriminant validity in this study. Table 4, which summarizes the results of the prediction model evaluation, shows that the prediction model in this study meets all the relevant evaluation criteria and provides a foundation for the reliability and validity of predicting evacuation behaviour.

Table 3. Fornell–Larcker criteria.

	CPRP	CMST	CPST	INVB	LEGK	PAST	RAST	RPEM
CPRP	-							
CMST	0.758	0.943						
CPST	0.823	0.658	0.911					
INVB	0.924	0.784	0.829	-				
LEGK	0.884	0.806	0.791	0.877	-			
PAST	0.821	0.728	0.723	0.833	0.797	0.938		
RAST	0.829	0.713	0.733	0.835	0.836	0.725	0.916	
RPEM	0.830	0.789	0.713	0.820	0.810	0.730	0.720	-

Note: The boxes with "-" are AVEs of formatively measured constructs not to be compared with the correlations.

Table 4. Final assessment results of the reflective model.

Latent Variable	Indicators	Loadings	Indicator Reliability [a]	Composite Reliability [b]	AVE [c]	Discriminant Validity? [d]
Proactive strategy	Information-seeking behaviour	0.937	0.530	0.936	0.879	Yes
	Evacuate immediately	0.938	0.537			
Reactive strategy	Waiting for notices from P.A	0.919	0.552	0.913	0.840	Yes
	Waiting in a secure location	0.914	0.539			
Competitive strategy	Trying to move in front of the others	0.941	0.522	0.941	0.899	Yes
	Disregard	0.945	0.539			
Cooperative strategy	Follow others	0.917	0.564	0.908	0.831	Yes
	Help others	0.906	0.533			

[a] Indicator reliability: indicators with outer loadings between 0.40 and 0.70 is considered for removal if deletion leads to an increase in composite reliability and AVE above the suggested threshold value. epoe_6 is retained when deletion does not increase in composite reliability and AVE above the suggested threshold value. [b] Composite reliability: the threshold value should be at least 0.70. [c] Average variance extracted (AVE): the significant value should be higher than 0.50. [d] Discriminant validity: the square root of the AVE of each construct should be higher than its highest correlation with any other construct.

In addition, the indicators of the measurement model need to be assessed for relevance and importance. The results of the co-linearity assessment of the measurement model indicators utilizing the variance inflation factor (VIF) are shown in Table 5, where the maximum

VIF value is 4.204 (INVB_5). The VIF values for all indicators are below the threshold of 5; thus, there is no co-linearity [81]. Furthermore, the analysis of the importance and relevance of the external weights of the measurement model indicators by the bootstrapping algorithm revealed that the indicators "INVB_4", and "INVB_6" were not significant in terms of survivability and "LEGK_1" in terms of the level of emergency knowledge. As the external model loadings for these indicators are 0.132, 0.832 and −0.006, respectively, "INVB_4" and "LEGK_1" are excluded and "INVB_6" is retained, even though the external weights of this indicator are not significant [80]. Moreover, a review of the mean, standard deviation t-value and p-value of the path coefficients revealed that the path coefficients of emotion on active, cooperative and passive strategies were not significant, suggesting that the above exogenous latent variables do not have a significant effect on the endogenous latent variables.

Table 5. Results for variance inflation factors.

Construct	Indicators	VIF
CMST	CMST_1	2.538
	CMST_2	2.538
CPRP	CPRP_1	1.520
	CPRP_2	2.221
	CPRP_3	2.387
	CPRP_4	2.405
INVB	INVB_1	3.593
	INVB_2	3.124
INVB	INVB_3	3.779
	INVB_4	1.087
	INVB_5	4.237
	INVB_6	3.589
	INVB_7	3.913
	INVB_8	1.032
LEGK	LEGK_1	1.009
	LEGK_2	2.498
	LEGK_3	1.411
	LEGK_4	1.891
	LEGK_5	2.16

Finally, a holistic assessment of the structural model is also required based on the above assessment. The holistic evaluation is based on the PLS algorithm, the blindfolding algorithm and the bootstrapping algorithm. Figure 3 shows the final structural model based on the above operations. With the bootstrapping algorithm, Figure 3 shows the path coefficients with significance between the decision-making capacity and the evacuation behaviour strategies. In addition, the coefficient of determination R^2 of the endogenous latent variable is assessed. R^2 values were classified as strong, medium or weak by the three values of 0.75, 0.5 and 0.25 [80], whereby the R^2 values for the four behavioural strategies can be considered to be quite large. On this basis, the relevance of the path model was evaluated with Blindfolding [80]. With the setting of omission distance = 7, the predictive correlation Q^2 for all four behavioural strategies is greater than 0, suggesting that the measurement model is relevant to the predictive model. Additionally, the effect size of f^2 in the model is reviewed by the PLS algorithm to measure the contribution of the measurement model to the R^2 of the prediction model. The f^2 values of 0.02, 0.15 and 0.35 indicate small, medium and large effects of exogenous latent variables on the values of endogenous latent variables in the structural model, respectively. The results show that the exogenous latent variables all contribute to the R^2 of the endogenous variables to varying degrees, and therefore the proposed measurement model can explain the behavioural strategies in the evacuation process. It suggests that the structural model proposed in this study is scientific. Based on the above research, we present in Table 6 the following formulaic structural equations for pre-evacuation and evacuation behavioural strategies pre-evacuation and evacuation.

Table 6. Structural equations for the evacuation behaviour strategy.

Evacuation Behaviour Strategies	Structural Equations
PAST	0.721 × (0.209 × LEGK + 0.246 × CPRP + 0.423 × INVB)
RAST	0.744 × (0.395 × LEGK + 0.440 × INVB)
CMST	0.709 × (0.379 × LEGK + 0.340 × RPEM + 0.172 × INVB)
CPST	0.716 × (0.177 × LEGK + 0.172 × CPRP + 0.384 × INVB)

5. The Development of the Prediction Model for the Efficiency of Evacuation

5.1. Defining the Model for Predicting Evacuation Efficiency

Based on the above analysis of the study, it was found that different components of decision-making capability could explain evacuation behaviours. Therefore, to predict evacuation efficiency, this study proposed a differential equation model for evacuation prediction by incorporating the explanation of decision-making capability for evacuation behaviours in the SEIR (Susceptible Exposed Infected Recovered) model of epidemics. As the SEIR model utilises data streaming to reveal the mechanisms of change in the number of patients at different stages of environmental and psychological and behavioural interactions [82], it is well suited for modelling public emergencies [23]. In this model, passengers are divided into four groups according to the state of the evacuation process: risk groups (R), which are prone to change state; pre-evacuation groups (P), which are groups that generate pre-evacuation behavioural strategies; evacuating-group (E), which is in the stage of an evacuation towards the exit and generates cooperative and competitive behavioural strategies during the evacuation process. Accordingly, when an emergency occurs, the composition and changes of the different states are as follows.

5.1.1. Risk Groups (R)

When an emergency occurs, passengers may not be aware of the need for an emergency evacuation. However, as the transmission of information during the outbreak of an emergency increases, passengers gradually begin to seek evacuation information. Groups in this state are influenced by groups around them that have already begun to exhibit pre-evacuation behaviours and gradually develop pre-evacuation behaviours.

5.1.2. Pre-Evacuation Groups (P)

As information about the emergency spreads, some groups actively seek information about the event to assess its severity, whereas others choose to wait for official instructions and do not actively seek information. This state of affairs leads to a shift towards evacuation groups.

5.1.3. Evacuating Group (E)

During the evacuation process, some groups will choose an orderly and cooperative strategy for evacuation. This group prefers to show altruistic tendencies in emergencies, whereas others will choose a competitive behavioural strategy. This group will initiate aggressive behaviour to ensure their safe evacuation, and this group will show altruistic tendencies. At the same time, the occurrence of aggressive behaviour also has a propagation effect leading to aggressive behaviour in some groups of the co-operative behaviour strategy. However, this competitive behaviour is not maintained all the time and orderly behaviour resumes after a certain period. The state of the evacuated group is therefore unstable. When the number of people around who adopt a competitive behaviour strategy is very high, passengers who adopt a cooperative strategy are influenced to gradually develop competitive behaviour. Additionally, when the number of people adopting a cooperative strategy increases around them, those adopting a competitive strategy will gradually become orderly.

5.1.4. Safe Groups (S)

As time passes, the evacuation process is gradually completed and the crowd is transformed from a dangerous crowd to a safe crowd.

5.2. RPES Model and Parameters for Evacuation

In this research, the following hypotheses are proposed to construct a model for evacuating passengers from metro platforms that incorporate decision-making capabilities:

(1) The evacuation model is divided into four categories of groups: the population at risk, the pre-evacuation group, the group during evacuation and the safety group. The ratios of each group to the total population at time t are denoted as R(t), P(t), E(t) and S(t), respectively. The initial state has only the at-risk population and the pre-evacuation group, and when t = 0, E(t) = 0 and S(0) = 0.

(2) In an emergency, no new people enter during the evacuation and the total number of people does not change during the evacuation, R(t) + P(t) + E(t) + S(t) = 1.

Therefore, this study proposes that the crowd state evolution relationship for the evacuation process is shown in Figure 4, and the main variables are described in Appendix A. Additionally, to simulate this evolutionary process, differential equations incorporating decision capabilities were constructed based on system dynamics and the model of epidemics.

$$\frac{dR}{dt} = \frac{-de(P_1 + P_2)}{N} - \rho R_t \tag{1}$$

$$\frac{dP_1}{dt} = -\frac{dR}{dt} - \frac{\lambda_1 P_1}{A_{coo}} - \frac{(1-\lambda_1)P_1}{A_{com}} + \frac{\alpha_1 R}{A_{act}} \tag{2}$$

$$\frac{dP_2}{dt} = -\frac{dR}{dt} - \frac{\lambda_2 P_2}{A_{coo}} - \frac{(1-\lambda_2)P_2}{A_{com}} + \frac{\alpha_2 R}{A_{pas}} \tag{3}$$

$$\frac{dE_1}{dt} = \frac{\lambda_1 P_1}{A_{coo}} + \frac{\mu_1\theta_1\delta_1 E_2}{A_{com}} - \nu_1\kappa_1 E_1 + \frac{\lambda_2 P_2}{A_{coo}} - \frac{\mu_2\theta_2\delta_2 E_1}{A_{coo}} \tag{4}$$

$$\frac{dE_2}{dt} = \frac{(1-\lambda_1)P_1}{A_{com}} + \frac{(1-\lambda_2)P_2}{A_{com}} + \frac{\mu_2\theta_2\delta_2 E_1}{A_{com}} - \frac{\mu_1\theta_1\delta_1 E_2}{A_{coo}} - \beta_2 E_2 \tag{5}$$

$$\frac{dS}{dt} = \nu_1\kappa_1 E_1 + \nu_2\kappa_2 E_2 \tag{6}$$

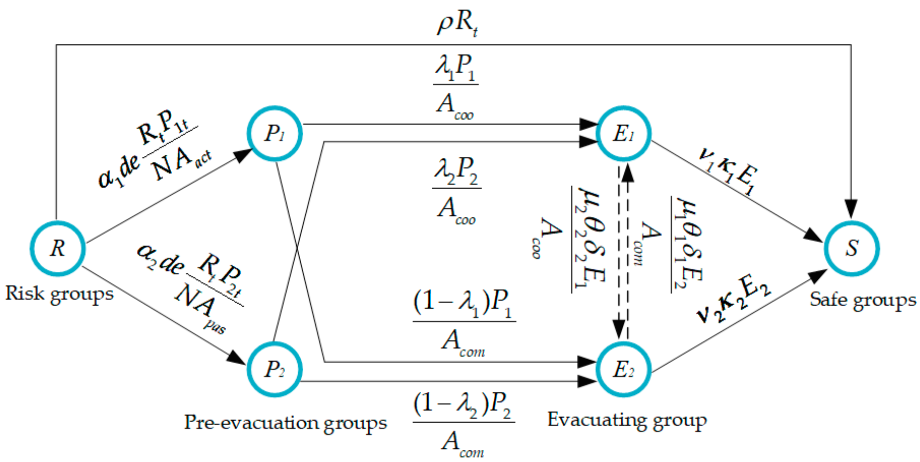

Figure 4. Model of the evolution of the state of the evacuated crowd on an underground platform.

Combining the above assumptions, this study used the system dynamics analysis software module in Anylogic to construct an RPES model for metro platform evacuation based on decision-making capability, with the structure shown in Figure 5.

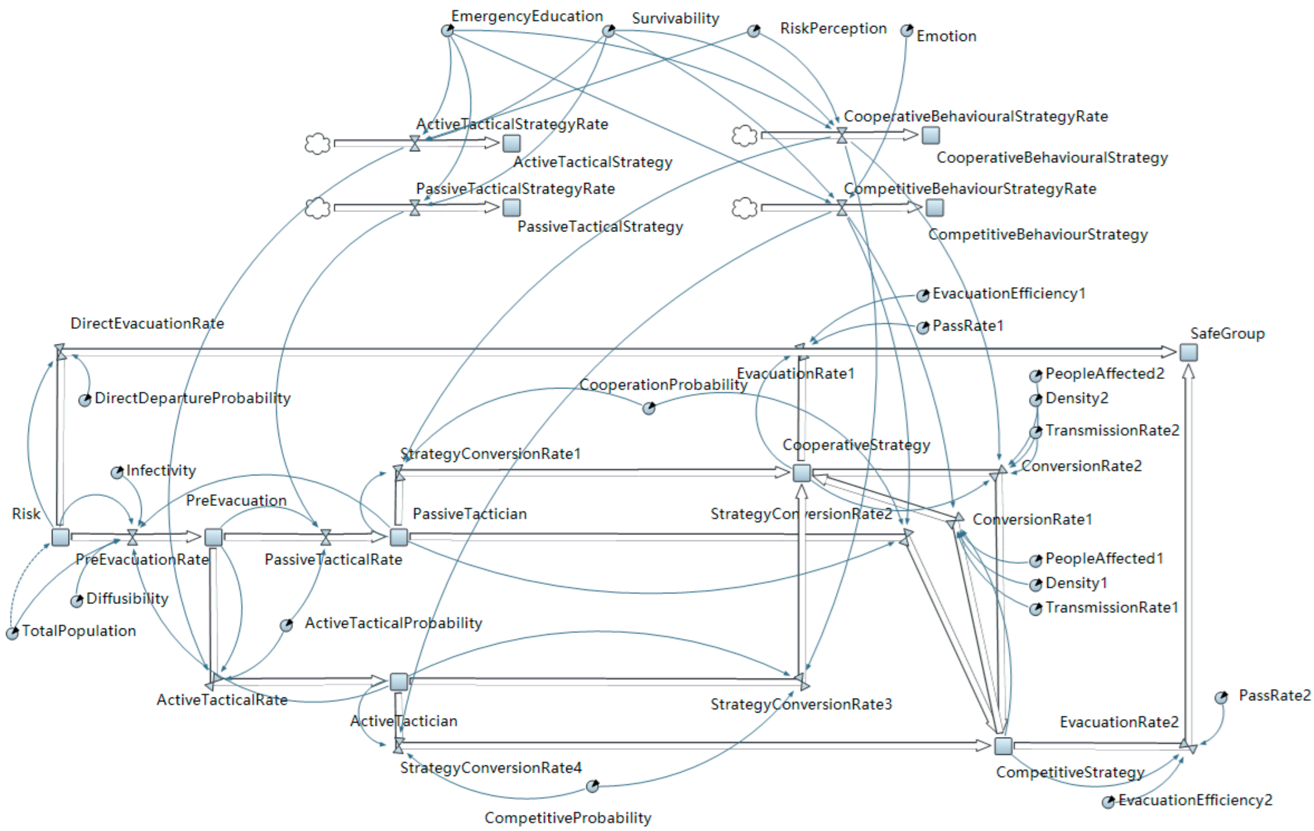

Figure 5. System dynamics model of the evacuation state evolution based on decision capabilities.

Following the model proposed in this study, assumptions are made about the parameters in the model and simulation studies are carried out based on this. The simulation experiment is as follows: Suppose there are 500 people on a metro platform, wherein in the initial state, the participant in 2 people adopt the active and passive strategies, respectively and propagate them. We assume that the diffusion rate of the evacuation message in the initial state is 1.25, the probability that passengers believe the evacuation message is true is 0.8, and the probability that passengers adopt different evacuation behaviour strategies is 0.5. In addition, passengers may transform between adopting cooperative and competitive strategies during the evacuation process; therefore, we assume that the crowd density during the evacuation process is 2.5 [83], and passengers who adopt competitive strategies can influence 1.5 surrounding passengers with a cooperative strategy with an effective probability of 0.6. Conversely, a passenger with a cooperative strategy can influence 2 surrounding passengers with a competitive strategy with an effective probability of 0.8. Assuming an exit throughput rate of 50 passengers/second, the impact of a passenger with a cooperative strategy and a passenger with a competitive strategy on evacuation efficiency is 1.3 and 0.8, respectively. The variation of the number of people in each group over time was obtained by substituting each parameter into the differential equation and the system dynamics model, as shown in Figure 6. To further determine the relationship between evacuation efficiency and decision-making capacity and to explore the quality of the model constructed in this study [84,85], sensitivity analysis was conducted on four parameters, Emotion, Emergency Education, Survivability, Risk Perception, where MIN (Emergency Education, Survivability, Risk Perception, Emotion) = 1, MAX (Emergency Education, Survivability, Risk Perception, Emotion) = 10, and step size = 1. The change in the number of people in each group in the model is shown in Figure 7 below.

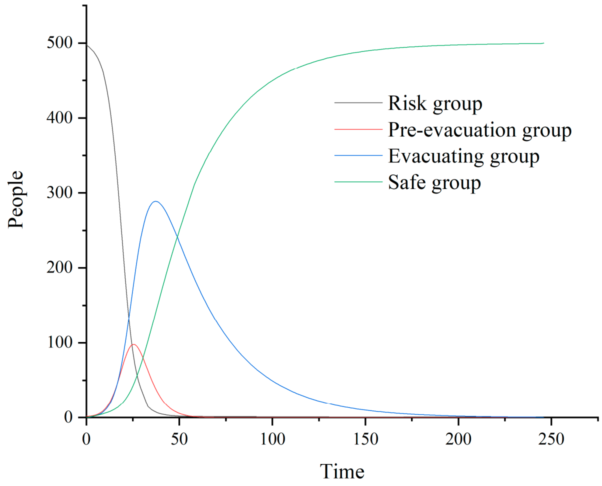

Figure 6. Graph of changes in numbers by group.

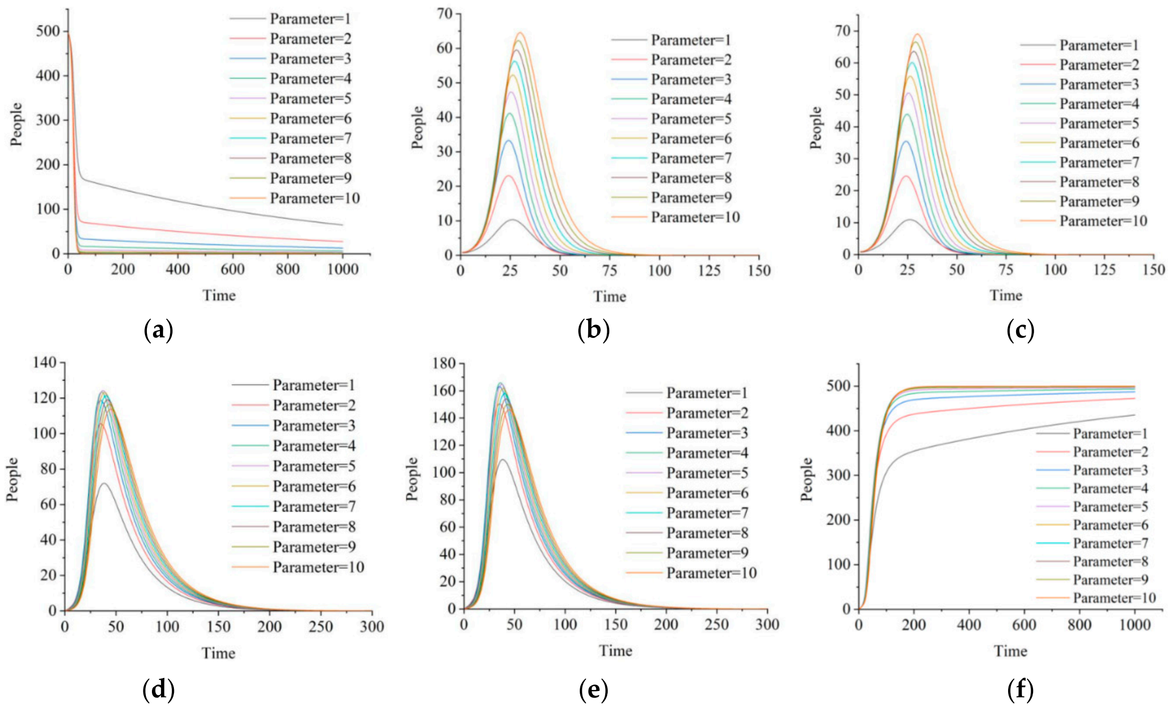

Figure 7. Sensitivity simulation for decision-making capability. (**a**–**f**) show the evolution of the number of 1 to 10 values for each component of decision-making ability for the risk, active strategy, passive strategy, competitive strategy, cooperative strategy and safety populations, respectively.

6. Result

In this research, two studies were carried out to incorporate decision-making capability in the prediction of evacuation efficiency. The structural equations based on the empirical study revealed that decision-making capability can have an extremely strong influence on evacuation behavioural strategies. For different behavioural strategies, the components of decision-making capability produce different levels of influence weighting. Of these, survival ability and level of emergency knowledge act on each evacuation behavioural strategy, with emotions acting only with competing strategies. Based on the simulations, it can be seen that the evacuation model proposed in this study revealed a decreasing trend in the overall population at risk, reaching zero at 50 s. The trend in the number of people in the pre-evacuation behavioural group and during the evacuation process was similar. In the simulation of this study, the evacuation was completed in the 200 s. Sensitivity analysis revealed a positive relationship between the number of people in the risk and safety groups as the value of the parameter increased, as did the conversion rate and the number of people converted. In this case, there is a clear distinction between the number of people when the parameter takes a value less than 6, whereas there is no clear distinction between the number of people and the conversion rate of these two groups when the parameter takes a value greater than 6. Among the pre-evacuation behaviour groups, the number of people adopting the passive behavioural strategy and the proactive behavioural strategy groups was consistent with the relationship between the decision-making capability parameter. The peak fluctuated between about 25 s and 37 s. The number of people adopting passive behaviours is greater than the number of people adopting proactive behaviours for the same value of parameters. The sensitivity analysis revealed that the highest number of people adopted cooperative behaviours when the parameter of decision-making capability took a value of 4, and the number of people adopting cooperative behaviours and the conversion rate gradually decreased when the parameter was greater than 4. For the group that adopts competitive behaviours, on the other hand, the highest number of people is found when the parameter takes the value of 5. When the parameter is greater than 5, the number of people decreases as the value of the parameter increases. The inflection point for the increase in the number of people in these two groups occurs around the 50 s under the influence of different parameter values. The relationship that exists between the change in the number of people behaving during evacuation in this study's model and the values taken for the decisional capacity parameter suggests that this study is correct in incorporating the parameter of decisional capacity in predicting evacuation efficiency and has good sensitivity in predicting evacuation efficiency.

7. Critical Discussions on Implications

This study rigorously constructs a system of indicators of individual decision-making capability regarding the prediction of strategies for evacuation behaviours by looking at a wide range of phenomena of evacuation behaviours, phenomena of phenomena in evacuation behaviours and lenses from other disciplines, guided by the anomaly-seeking approach and the systems paradigm of relationship development. This cross-disciplinary approach is innovative in that it rigorously introduces a conceptual framework of decision-making capability that bridges the gaps in previous research. A common anomalous component in studies of evacuation behavioural strategies is the influence of emotion on behaviours, which is then supplemented by the introduction of risk perception competencies, survival competencies and levels of emergency knowledge to the measurement model. The influence of the components of decision-making capability on evacuation behavioural strategies is analysed through the development of partial least squares equations, and the specific dimensions of evacuation behavioural strategies are also identified.

The empirical study reveals that there is no significant effect of emotion on proactive, passive and cooperative behavioural strategies. This indicates that they are more emotionally calm, although most will experience anxiety. For those with a tendency towards competitive strategies, however, their emotions were dominated by negative emotions of fear and dread. Although the panic theory is no longer applicable, negative emotions were still found to influence competitive behavioural strategies. It fits with the current view of assessing evacuation efficiency from the perspective of emotional contagion.

In contrast, survival ability, an important aspect of evacuation behaviours, has an impact on each of these behaviours. Incorporating factors such as cognition and personality also meet the current need to explore the efficiency of evacuation through individual differences. For survival ability, this study found that it had a significant impact on both pre-evacuation behaviours and cooperative behavioural strategies. This aspect was tended among those who chose both proactive and cooperative strategies, both of whom may have clear attitudes to improve their state in life or not, whereas there was no clear distinction between those who tended to other behavioural strategies. In addition, individuals who tend to be cooperative are more socially responsible and tend to be more socially responsible and "altruistic".

The groups inclined towards passive and competitive behavioural strategies, on the other hand, showed a more dramatic response to emergency emotions and therefore they may try to regulate their emotions through cues. Management can focus on the disclosure of information during evacuation guidance, which can help negative-emotion groups recover emotionally to reduce the occurrence of competitive behaviours.

The SEM indicates that the level of emergency knowledge is also an important aspect of the behavioural assessment. In the survey, it was found that the group with a clear tendency towards passive behavioural strategies mostly indicated that they were not familiar with the use and location of fire-fighting facilities, and therefore they were more likely to wait for public announcements to guide and rescue them. In contrast, pedestrians with a clear tendency towards proactive behavioural strategies were more familiar with the use and location of fire-fighting facilities, and they were likely to be the first to take fire-fighting measures or evacuate in the face of a catastrophic event.

In addition, groups with a clear tendency towards pre-evacuation behaviour and in-process behaviours are more cognisant of cues. However, for groups that were not as strong in cue perception, they did not have a clear distinction between evacuation behavioural strategies during the evacuation process. It could be because individuals with a tendency towards passive strategies trust official guidance more and those with a tendency towards competitive strategies prefer to be the first to escape and may not show a higher level of risk perception. This is consistent with the finding that risk perception ability does not seem to explain the adoption of passive and competitive behavioural strategies through the structural model analysis of this study. Based on this part of the study, the following recommendations are made in evacuation management: (1) during the evacuation process, emergency departments should channel the emotions of pedestrians, so that the emotions of the evacuated crowd remain as calm as possible or are restored as soon as possible, so as not to cause mass panic and reduce the number of people adopting competitive behaviour strategies; (2) attention should be paid to the daily maintenance of emergency signs to ensure that they can perform their functions during evacuation. The emergency management department should also pay attention to the disclosure of evacuation reasons to reduce panic, enhance the group's sense of social responsibility, and promote the group to adopt cooperative behaviour to avoid competition; (3) fire-fighting facilities are stored in safe and prominent locations, and the use of fire-fighting facilities is marked, which helps to improve evacuation efficiency; (4) training and education of emergency knowledge are strengthened to enhance passengers' risk perception ability.

To further discuss the influence of decision-making capability on evacuation, differential equations are constructed based on an epidemic model to discuss the evolution of crowd size in each state during evacuation. Finally, all findings were integrated into the system dynamics. The results of the sensitivity analysis proved the good sensitivity of the model to the decision-making capability.

This study combines two methods, PLS and epidemic modelling, both of which have predictive functions. The conceptual framework and model proposed by integrating contemporary perspectives on psychological and cognitive influences on conduct advances evacuation prediction and complements the single perception of evacuation efficiency assessment in previous studies. This study provides a basis for researchers to further examine research on assessing evacuation efficiency and explore theories of evacuation behaviours through an interdisciplinary approach. Furthermore, this study contributes to the practice of emergency management by providing a model to guide crowd evacuation in the prediction of evacuation efficiency on metro platforms. This study proposes that the theory and model are useful, especially when it is difficult to obtain actual data on evacuation behaviours.

8. Conclusions

It is feasible to incorporate decision-making capability in predicting the efficiency of the evacuation of passengers on metro platforms. It provides some valuable insights into the field of evacuation prediction. This research revealed the relationship between decision-making capability and evacuation behaviours. In addition to analysing each behavioural strategy in terms of its representation of decision-making capability, this research combines this relationship with an epidemiological model to construct a predictive model of evacuation efficiency to simplify the assessment of evacuation efficiency. This allows the assessment of evacuation efficiency in advance by a simple input of the score of decision-making capability and the probability of occurrence of the behavioural strategy. Thus, the presentation of this conceptual framework bridges an interdisciplinary knowledge gap in this field and this model also provides a model with scalable predictions of evacuation efficiency, which provides a new idea for subsequent research. Overall, this study is useful in the field of evacuation prediction. It has inspired several directions for future research, including the inclusion of factors for people with reduced mobility, and the nature of emergencies to make the model for evacuation efficiency assessment more comprehensive and useful. It also develops evacuation efficiency prediction models to cover other application areas, such as the evolution of business operating processes, transportation and structural optimisation. However, there are certain shortcomings in this study. However, there are certain shortcomings in this study, as actual disaster data are difficult to obtain, and this research is limited to obtaining information on the relationship between decision-making capability and evacuation behaviours in the form of interviews. Secondly, to simplify the complexity of individual interaction with the environment, this study did not incorporate the influence brought about by the spatial aspects of the environment into the construction of the model. However, as the morphological structure of the environmental space not only affects the movement rate of evacuees, but also the atmosphere of insecurity brought about by the damage to the environment could have an impact on the decision making of the crowd. In future research, it will be an important direction to develop and incorporate the mechanisms by which environmental space affects decision-making capability and evacuation behaviours in different dynamic disaster scenarios based on meta-analysis in order to improve evacuation prediction accuracy.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare that there are no competing interest.

Appendix A

Table A1. Description of the main simulation variables.

Category	Variables	Explanation of Variables
Variable of state	Risk	Groups that are not occurring but are about to adopt evacuation behaviour strategies
Variable of state	PreEvacuation	Groups that have become aware of evacuation and have adopted pre-evacuation behavioural strategies
Variable of state	PassiveTactician	Groups that adopt passive behavioural strategies
Variable of state	ActiveTactician	Groups that adopt proactive behavioural strategies
Variable of state	CooperativeStrategy	Groups that adopt cooperative behavioural strategies
Variable of state	CompetitiveStrategy	Groups that adopt competitive behavioural strategies
Variable of state	SafeGroup	Groups that have been successfully evacuated and are in a safe condition
Variable of state	ActiveTacticalStrategy	A state of transformation into a proactive behavioural strategy
Variable of state	PassiveTacticalStrategy	A state of transformation into a passive behavioural strategy
Variable of state	CooperativeBehaviouralStrategy	A state of transformation into a cooperative behavioural strategy
Variable of state	CompetitiveBehaviourStrategy	A state of transformation into a competitive behavioural strategy
Variable of rate	ActiveTacticalStrategyRate	Formation of proactive strategies (SEM)
Variable of rate	PassiveTacticalStrategyRate	Formation of passive strategy (SEM)
Variable of rate	CooperativeBehaviouralStrategyRate	The formation of a cooperative strategy (SEM)
Variable of rate	CompetitiveBehaviourStrategyRate	Formation of a competitive strategy (SEM)
Variable of rate	DirectEvacuationRate	The probability that passengers, due to their geographical location, are virtually unaffected by emergencies, translating directly into a safe group ρR_t
Variable of rate	PreEvacuationRate	Groups that are already aware of the need for evacuation behaviour, but have not yet adopted behavioural strategies $\frac{-de(P_1+P_2)}{N}$
Variable of rate	PassiveTacticalRate	The conversion rate of passengers adopting a passive strategy $\frac{\alpha_2 R}{A_{pas}}$
Variable of rate	ActiveTacticalRate	The conversion rate of passengers adopting proactive strategies $\frac{\alpha_1 R}{A_{act}}$
Variable of rate	StrategyConversionRate1	The conversion rate of passengers who first adopt a passive strategy and then convert to a cooperative strategy $\frac{\lambda_2 P_2}{A_{coo}}$
Variable of rate	StrategyConversionRate2	The conversion rate of customers who first adopt a passive strategy and then convert to a competitive strategy $\frac{(1-\lambda_2)P_2}{A_{com}}$
Variable of rate	StrategyConversionRate3	The conversion rate of passengers who first adopt a proactive strategy and then convert to a cooperative strategy $\frac{\lambda_1 P_1}{A_{coo}}$
Variable of rate	StrategyConversionRate4	The conversion rate of passengers who first adopt a proactive strategy and then convert to a competitive strategy $\frac{(1-\lambda_1)P_1}{A_{com}}$
Variable of rate	ConversionRate1	The conversion rate of passengers who adopt a competitive strategy to a cooperative behavioural strategy as they gradually regain their composure $\frac{\mu_1\theta_1\delta_1 E_2}{A_{com}}$
Variable of rate	ConversionRate2	The conversion rate of passengers who adopt a cooperative strategy to a competitive behavioural strategy due to the surrounding influences $\frac{\mu_2\theta_2\delta_2 E_1}{A_{coo}}$

Table A1. *Cont.*

Category	Variables	Explanation of Variables
Variable of rate	EvacuationRate1	The conversion rate of passengers who adopt cooperative behavioural strategies to a safe state $\nu_1\kappa_1E_1$
Variable of rate	EvacuationRate2	The conversion rate of passengers who adopt a competitive behaviour strategy to switch to a safe state $\nu_2\kappa_2E_2$
Parameter	EmergencyEducation	Level of emergency knowledge, one of the parameters of decision-making capability
Parameter	Survivability	Survival capacity, one of the parameters of decision-making capability
Parameter	RiskPerception	Risk perception, one of the parameters of decision-making capability
Parameter	Emotion	Emotional response, one of the parameters of decision-making capability
Parameter	DirectDepartureProbability	Probability of direct conversion to safe groups ρ
Parameter	Infectivity	The proportion of passengers affected by other passengers who have adopted pre-evacuation behavioural strategies e
Parameter	Diffusibility	The diffusion rate of pre-evacuation behavioural strategies d
Parameter	TotalPopulation	Total number of people on metro platforms N
Parameter	ActiveTacticalProbability	The probability that the crowd tends to adopt a proactive strategy α_1
Parameter	CooperationProbability	The probability that passengers who adopt a passive strategy will then adopt a cooperative strategy λ_2
Parameter	CompetitiveProbability	The probability that passengers who adopt a proactive strategy will then adopt a cooperative strategy λ_1
Parameter	PeopleAffected1 PeopleAffected2	Number of passengers who adopt competitive behavioural strategies to influence those around them μ_1 Number of passengers who take cooperative behavioural strategies to influence those around them μ_2
Parameter	Density1 Density2	Density during the evacuation of competing behavioural strategies passengers θ_1 Cooperative behavioural strategies density during passenger evacuation θ_2
Parameter	TransmissionRate1 TransmissionRate2	The mutual conversion rates of passengers who adopt a competitive behavioural strategy and those who adopt a cooperative behavioural strategy, respectively δ_1, δ_2
Parameter	EvacuationEfficiency1 EvacuationEfficiency2	denoted as evacuation efficiency for passengers with cooperative and competitive strategies, respectively ν_1, ν_2
Parameter	PassRate1 PassRate2	Passage rates at the exit for passengers with cooperative and competitive strategies, respectively κ_1, κ_2

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