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Future-proofing Klang Valley's veins with REBET: A framework for directing transportation technologies towards infrastructure resilience

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ABSTRACT

The transportation industry is in the midst of a revolution with technologies, such as shared vehicles, drones, and autonomous vehicles, that are poised to reshape the way we move. Yet, the multitude of technologies present a difficulty in prioritizing which technologies should be invested in. While focusing on Klang Valley's transportation system, this research proposes the REsilience Brittleness and Emerging Technologies (REBET) framework, which aims to identify the transportation technologies with the highest potential of strengthening the system's resilience. We used a Dephi technique to identify the Sources of Brittleness (SBs) in the system and technologies with the highest relevance to the Malaysian setting. Using multiple linear regression, we then derived a relationship between the two aspects. The framework defines the relative resilience of the technologies according to their forecasted ability to eliminate system brittleness. The results ranked 23 technologies, with the topmost recommendations being ITS, Big Data, and Smart Buses. We highlight REBET's robustness as a global decision-making tool for infrastructure managers, researchers, and policymakers to identify ideal technologies for their transportation systems.

1. Introduction

Klang Valley is at the heart of West Malaysia, with a population of approximately 7.5 million and an area of around 2,800 square kilometres (DOSM, 2020). The urban region accommodates a variety of transportation options, including 11 rail lines, several bus operators serving different corridors, private taxis, as well as new technology-powered options such as e-hailing, car-sharing, e-scooters, and more. However, the urban sprawl has caused the region to be highly dispersed, with many satellite cities out of reach of the public transport lines. In addition, the flow of traffic in and out of the Kuala Lumpur City Centre (KLCC) exceeds 3 million vehicles daily, causing the centre to approach a gridlock (Yusoff et al., 2021). Instead of raising the use of public transport as per the 2020 goals, the modal share of public transport declined from 20% in 1997 to around 11% in 2017 (Shokoohi and Nikitas, 2017). The decline can be partially attributed to the national strategy of promoting local automobile manufacturers as well as the mindset associated with owning a car (Lim and Lee, 2012; Shariff, 2012). The Kuala Lumpur Structure Plan 2020 (DBKL, 2018) acknowledged sources of vulnerability in the transportation system, including insufficient measures to accommodate capacity, inadequate interchange facilities in public railway stations, unreliable taxi services, all of which directly weaken the system's resilience (Ariffin and Zahari, 2013).

The United Nations defined *resilience* as *"The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions"* (United Nations, 2009, p. 24). As the stresses on the Klang Valley's transportation system rise, especially with regards to the imbalanced use of transportation modes, the system is likely to be approaching a state of brittleness. Brittleness is the opposite, or rather, the lack of resilience in the system (Jackson, 2010). To prevent the system from further progressing towards brittleness, an investigation is required to identify the probable causes of this trend and the ideal investment areas that can strengthen the system's resilience. This research specifically looks into the latest transportation technology advancements which can offer an opportunity to tackle brittleness. The framework developed does not investigate a predefined set of technologies but instead identifies the most relevant set of technologies through a qualitative study, which is the framework's first step.

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While multiple approaches of resilience assessment have been developed (Ahmed and Dey, 2020), researchers have shown that it still remains a challenge to identify when a system is drifting towards brittleness (Jackson, 2010). Many current mathematical approaches for tackling this fall short of forecasting the effects of technological supplementation to the system (Do and Jung, 2018; Hossain et al., 2019; Tang and Heinimann, 2018) and commonly fail to take the social dimension of resilience into account along with the technical, economic, and organizational aspects (Berche et al., 2009; Ding et al., 2015; Hartmann, 2014; Kaviani et al., 2017; Zhang et al., 2015). The critical point this research seeks to examine is the decision-making process of technology investments corresponding to a local level of brittleness. The REsilience, Brittleness and Emerging Technologies (REBET) framework aims to identify transport technologies with the highest potential of drifting urban mobility systems towards resilience. Through a qualitative study, the framework first identifies the Sources of Brittleness (SBs) in Klang Valley, which are the disruptions or issues weakening the system, and a list of the technologies with the highest relevance to the Malaysian situation. Subsequently, linear regression along with the framework's assumptions, defined in Section 3, derive a relationship between the Technologies and the Sources of Brittleness. Finally, a scoring system of the relative effect of each technology on the system's resilience produced a recommended list of technologies. Due to the multitude of emerging technologies, the novelty of this research and its main contribution lies in the methodology of identifying the ideal set of technologies with a high positive impact on resilience that should be invested in for research and development.

This paper begins by covering the previous literature related to the topic. In Section 2, the scope of the research, its theoretical background, and the motivation for conducting the research are discussed. Subsequently, Section 3 details the assumptions upon which the research is based followed by an in-depth discussion of the research methods. Next, Section 4 presents the results from the different stages of the methodology along with an interpretation and discussion of the findings. Finally, Section 5 concludes the paper by highlighting a summary of the main results in addition to discussing the limitations of the study and recommendations for future research.

2. Literature review

As the goal of the developed framework is identifying emerging technologies with the most significant positive impact on the resilience of Klang Valley's transportation system, the theory behind identifying a relationship between technologies and resilience is sketched out in Section 2.1. The following questions lay out the structure of that section:

1. What is resilience under the context of this research?
2. What system is the research investigating?
3. What is the relationship between brittleness and resilience?
4. What is a technology, and how can it be linked to resilience?

While framing these questions, we envisaged their answers to provide the necessary fundamental background for the proposed framework. In Section 2.2, we build upon the fourth question by discussing the previous work that has been done in pursuit of investigating the relationship between technologies and infrastructure resilience. This is concluded by the research gap which the REBET framework aims to fill.

2.1. Theoretical background

1. What is resilience under the context of this research?
While the term "resilience" has made its way through various fields of science and management (Meerow et al., 2016; Roostaie et al., 2019), there remains a consensus on the fundamental concept despite having been redefined in many domain-specific manners. Under the context of this research, we find the most relevant definition to be the definition by the United Nations, as mentioned in Section 1. This definition refers to, not only the technical system, but also the societal aspect.

2. What system is the research investigating?
The term infrastructure covers a wide range of systems and facilities that serve a country, however, there exists a narrower term called critical infrastructure defined as *"water, wastewater, power, transportation, and telecommunications systems without which buildings, emergency response systems, dams, and other infrastructure cannot operate as intended." (National Research Council, 2009, p. vii)*. This study solely focuses on the transportation system in the region of Klang Valley, investigating the resilience of urban mobility in this specific region. The term urban mobility was split into three main categories by Rodrigue et al. (2013): (1) collective transportation, (2) individual transportation, and (3) freight transportation. The scope of this research is limited to collective (commonly known as public transit) as well as individual transportation (any mode of mobility that is taken as a result of personal choice). While freight transportation shares critical infrastructure with the other two categories of transport and there exists critical interdependencies between the three categories, the scope of this research was focused on passenger transport. Within Klang Valley, passenger transport and transportation of goods are two separate industries with their respective stakeholders and minimally co-dependent dynamics. Therefore, a separate investigation would be more suitable to efficiently cover the technologies and sources of brittleness within freight transportation. The REBET framework can be easily adapted for freight transportation and other forms of systems.

When it comes to resilience, each system has four dimensions. Commonly, engineering-based systems like transportation focus on the resilience of the physical system. However, this research goes beyond by exploring the four dimensions of resilience – technical, organizational, economic, and social resilience (TOSE) (Bruneau et al., 2003). In addition, the REBET framework applies these dimensions to the concept of brittleness. Bruneau et al. (2003) defined the four dimensions as follows: **Technical resilience** refers to the physical components' ability to withstand negative impacts and continue to perform at the required level. **Organizational resilience** refers to the body managing the transportation system, which is responsible for decisions taken in the case of crisis as well as continuously enhancing the system's resilience properties: Robustness, Redundancy, Resourcefulness, and Rapidity. **Social Resilience** aims to mitigate the negative consequences endured by the communities and governments which have undergone a disruption. Lastly, **economic resilience** is designed to lessen the direct and indirect economic losses caused by the disruption.

3. What is the relationship between brittleness and resilience?
Multiple studies choose to assess resilience directly through concentrating on the physical attributes of the system as well as the probabilities of occurrence of a major event or disruption (Alipour and Shafei, 2016; Aydin et al., 2018; Cox et al., 2011; Donovan and Work, 2017; Mojtahedi et al., 2017), however, only a few studies acknowledge the effect of existing system weaknesses on the consequences of a disruption. Jackson (2010) highlights the importance of system brittleness, which refers to the opposite or the lack of resilience. Although it is common to consider accidents and disruptions as completely arbitrary, a different school of thought states that prior to major system failures, weaknesses in the system, more scientifically known as sources of brittleness, drift the system towards greater consequences. The majority of high risk, low probability events are challenging to foresee, yet, strengthening the system's overall reliability can bolster its resilience to such events. Saurin and Carim Junior (2012) elaborated further on the concept of brittleness where they distinguished between two assessment points, namely, Sources of Brittleness (SBs) and Sources of Resilience (SRs). SBs were identified as factors that counteract the system's performance, pushing it

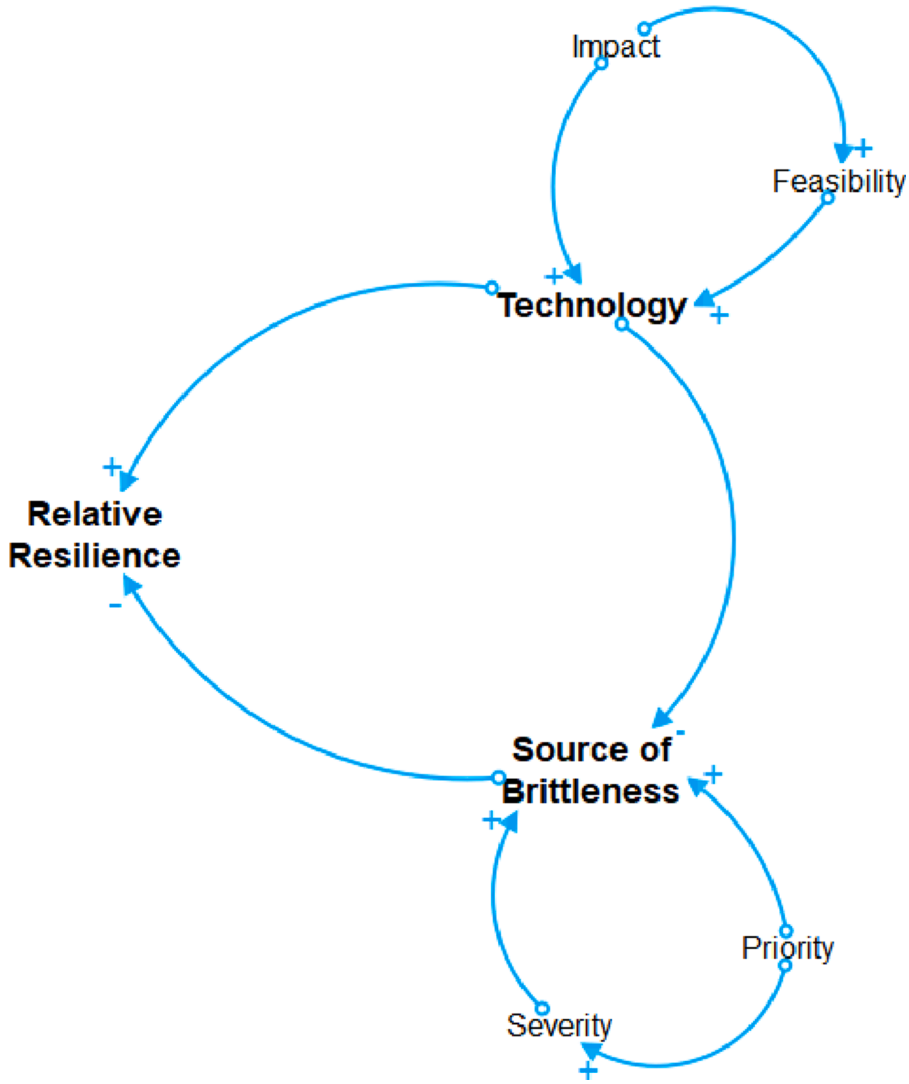

Fig. 1. An illustration of the underlying concept of the REBET framework.

towards its limits. Under this research, SBs are the weaknesses in the transport system of Klang Valley. On the other hand, SRs are factors that support the system's performance, aiding the continuity of optimal functioning even in the case of an unanticipated disturbance. Under this research, technologies are investigated as potential SRs in the system. According to Woods (2007), any brittle system does not possess the ability to adapt to unexpected disruptions and falls apart under stress. Hence, it is crucial to prevent the drifting of a system towards a state of brittleness and ensure that technological investments work towards eliminating sources of brittleness.

4.What is a technology, and how can it be linked to resilience? Wahab et al. (2011) reviewed the concept of technology and its definitions. Under the context of this research, a technology can be (1) a physical component such as equipment, infrastructure, blueprints, techniques, processes or (2) an informational component that consists of know-how in management, marketing, production, quality control, reliability, skilled labor and functional areas. The advancement of information and communications technology (ICT) in transportation is revolutionizing the industry by changing the processes of how transportation functions (Gössling, 2017). The adoption of shared bikes, cars, and e-scooters was rising before the pandemic (Mouratidis et al., 2021). Drones are being used for the delivery of packages and surveillance measures. Autonomous vehicles are being tested in many regions around the world. The more technologies that emerge within the field, the more difficult it will be to identify which of these technologies should be prioritized within a specific geographical region. *How can we know which technologies should we invest in that would strengthen our transportation system?* The REBET framework answers this question by providing a method that identifies the technologies that should be prioritized in a specific region by ranking their potential impact on the system's resilience. It is important to note that in this investigation, there is no predefined set of technologies that the researchers decided on. The list of technologies is derived through interviews with experts, which narrows down the set of technologies to feasible and relevant ones to the geographical area under investigation.

2.2. Prior research

Recently, Brown and Soni (2019) examined the effect of electric vehicles on grid resilience in the United States. Using the Delphi method, ten experts participated in evaluating the influence of different types of vehicle-to-grid integrations on grid resilience from their opinion. Janušová and Čičmancová (2016) correlated the functions or components of Intelligent Transport Systems (ITS) with potential applications in the protection and resilience of transportation infrastructure. However, the correlation was purely based on examples of possible implementation in different scenarios with no investigation into the actual

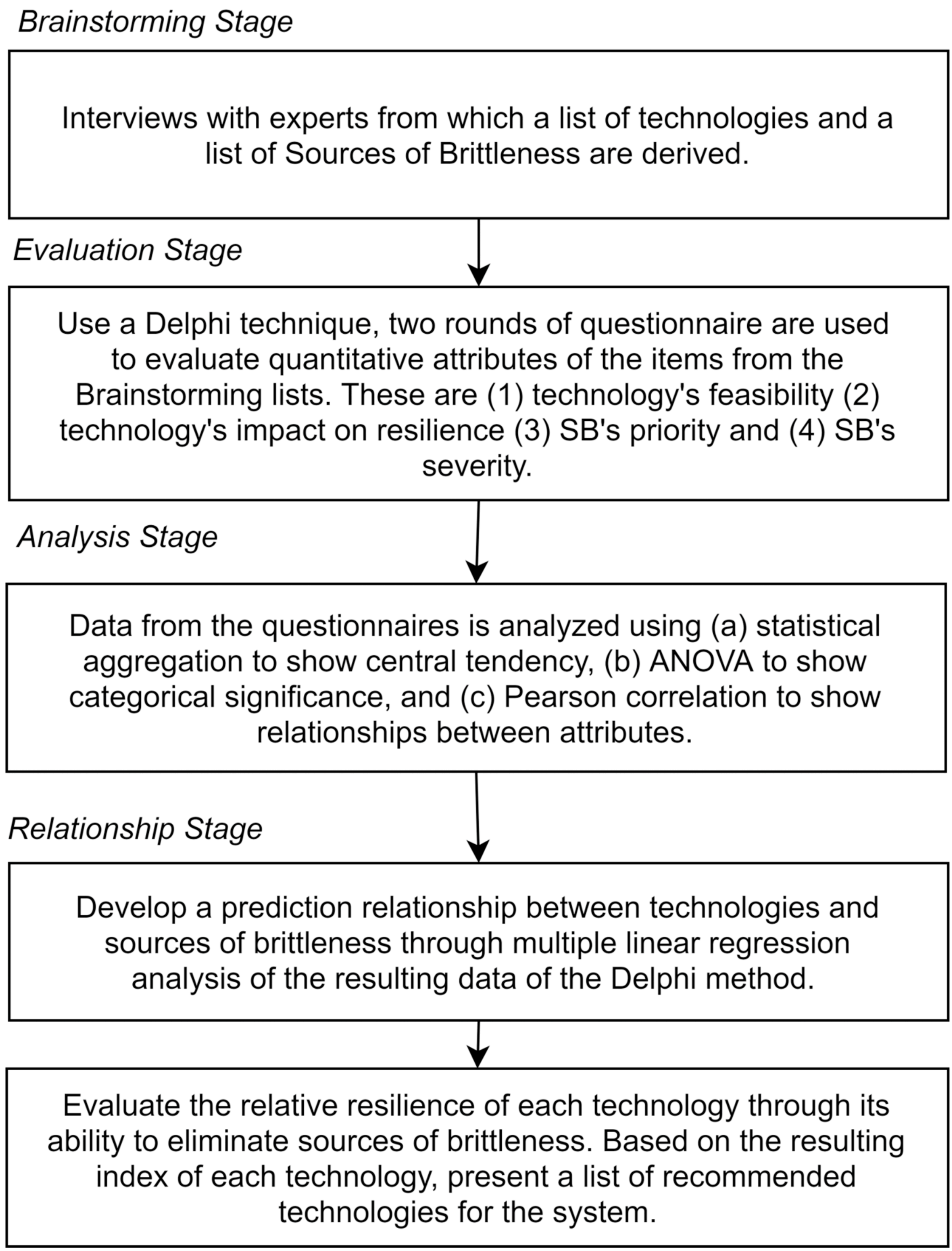

Fig. 2. REBET Framework Steps.

impact or a case study comparison. Ding et al. (2015) modelled the public rail transit network in Kuala Lumpur using network theory. They investigated the growth of the network as well as the manners of failures in response to different attack strategies. Markolf et al. (2019) presented direct and indirect pathways to disruption of transportation systems corresponding to various climate effects. Their study aims to shift the focus from being entirely centred on system robustness to incorporating more social factors through flexibility and agility. Labaka et al. (2016) developed a holistic framework of identifying the best policies for enhancing infrastructure resilience. The study included 3 phases (i) Identification of the Resilience policies (ii) Development of the influence table (iii) Development of the implementation Methodology. Through a Delphi Technique, 15 experts determined the list of policies with the strongest influence in relation to the three stages of resilience: prevention, absorption, and recovery.

In conclusion, there have been investigations in the literature providing an understanding of the impact of specific technologies on certain infrastructure, as well as, the effects of disruptions on the infrastructure. However, the REBET framework has been developed to identify the technologies with the highest influence on infrastructure

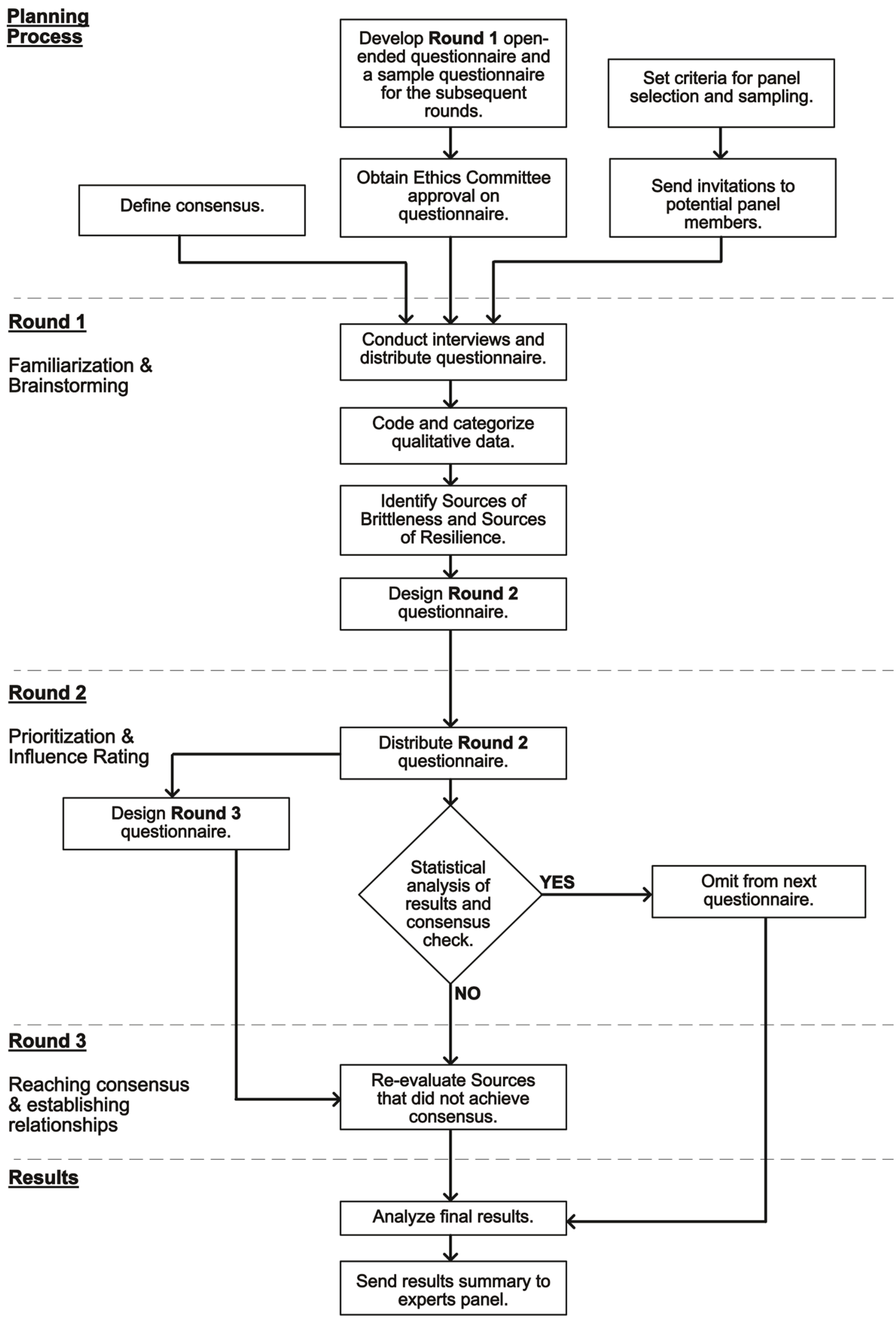

Fig. 3. A detailed breakdown of the steps taken for the planning and execution of the Delphi Method.

resilience. The final list produced through this research was derived from the interviews and quantitative data collected from the experts. As discussed in Section 2.1, the multitude of emerging technologies in the field of transport demands a method for governments, investors, and researchers to be able to identify which technologies are ideal for their specific situation. The REBET framework fills this research gap by presenting a step-by-step method towards identifying these technologies.

3. Methodology

3.1. Research framework

In order to change something about a system, we must first understand the dynamics of that system. As seen in Fig. 1, the research question relies on three main components: (1) Technologies, (2) Sources of Brittleness, and (3) the Resilience of the system. The figure shows how this research assumes the relationships between these three elements. Firstly, technologies are regarded as potential Sources of Resilience. The term potential is used because it must be taken into account that Technologies can also be a Source of Brittleness. For example, certain technologies can cause cyber security vulnerabilities or lead to increased congestion. As this research aims to identify which technologies can contribute most to the resilience of the system, technologies are evaluated based on their potential ability to reduce/eliminate sources of brittleness. Therefore, the technologies which can tackle the most severe and important sources of brittleness are the technologies with the highest contribution to the system's resilience.

The framework is divided into four main stages as shown in Fig. 2. In order to identify the technologies with the highest contribution to Klang Valley's resilience, we needed to investigate technologies that were prominent in the region and identify which sources of brittleness were strongly causing the system to be vulnerable. Therefore the first step of the framework was to interview experts with the following questions guiding the conversation:

1. In your opinion, what are the most crucial issues/stresses that are currently affecting the urban transportation system in Klang Valley?
2. In your opinion, what are the technologies dominating the technological advancement in Klang Valley's transportation industry? (Technologies already introduced in Malaysia)
3. What are the main barriers that affect the adoption of a new transport technology in Klang Valley?
4. Which emerging technologies have the ability to change the trends that are currently being followed on the road and other transport systems? (New technologies not yet introduced in Malaysia)
5. How would you correlate the technologies you suggested to mitigate the major stresses affecting the infrastructure? You can state any potential methods of implementation at different stages of the infrastructure's life cycle.

Through the analysis of these interviews, three lists were derived upon which the research is based. The three lists are: (1) a list of prominent and emerging technologies in the region, (2) a list of stresses and barriers weakening the system, and (3) a list of possible improvements to the system. These lists were then iterated through questionnaires and statistical methods to reach a final ranking for the technologies with the highest potential. The subsequent sections describe, in detail, how the research conclusions were reached and the Delphi Method upon which the data collection stages were based.

3.2. The Delphi method

The first two stages of the framework are based on the well established Delphi Technique, a commonly used method for calculating and aiding in both forecasting and decision-making in several disciplines since its implementation at the RAND Corporation over 60 years ago (Helmer et al., 1959). The uniqueness of this methodology lies in deriving unanimous results among the experts through iterations that achieve consensus without the interference of psychological factors. The Delphi Method is employed in this research to identify Sources of Brittleness (SBs) in the urban mobility system of Klang Valley as well as to project the latest technologies that must be prioritized to build system resilience. The four main features uniquely attributed to a Delphi study are defined as follows Rowe and Wright (1999): 1) **Anonymity** - the identities of the panel members are not disclosed to the fellow experts throughout the study duration and remains strictly confidential to the research team. Anonymity tackles social pressures that exist in focus groups and meetings, such as dominant voices and fear of being judged. 2) **Iteration** - the research questionnaire is run over multiple rounds granting individuals the ability to change their opinions in light of the views of other experts in the preceding round. 3) **Controlled feedback** - every round provides feedback of the previous round to each expert regarding the collective opinion of the panel, often represented in the form of a statistical summary, and 4) **Statistical aggregation** - the experts' responses are combined and presented using summarized statistical values including statistical average (mean/median) and standard deviation.

The Delphi Method has been applied in multiple studies related to technological forecasting. One of the most recent applications of the Delphi Method with regards to the future of transportation was carried out by Melander et al. (2019). Forty experts participated in investigating the probability, desirability, and impact of different projections in 6 key transportation areas. Liimatainen et al. (2014) combined the Delphi methodology with a mathematical approach to develop an accurate forecast of the future of carbon dioxide emissions of road freight in Finland. Schuckmann et al. (2012) carried out a global study with 354 experts aiming to develop a clear direction of the factors that will affect the transport infrastructure development up to the year 2030. Nazarko et al. (2015) conducted a nationwide study in Poland consulting 150 experts to identify the deficient areas of research in the field of road and bridge construction and subsequently develop a foresight of the direction of materials and technologies that must be prioritised within the next 30 years. In the surveys distributed, the experts were required to (1) judge the importance of the technologies under consideration, (2) estimate the likelihood of the technology implementation within a given time, and (3) evaluate barriers and factors which influence the implementation of these technologies.

As shown in Fig. 3, the process was divided into three rounds: (1) Round 1: Familiarization and Brainstorming - An open-ended questionnaire is developed to brainstorm a list of the Sources of Brittleness (SBs) that cause weakness in the system and a list of the technologies with the potential to build resilience against the identified SBs. This round was mainly conducted through a face-to-face interview, Skype or phone call meeting. (2) Round 2: Prioritization and Influence Rating - A structured questionnaire, that summarizes the results of the first round, was distributed to the experts to generate quantitative values for the qualitative results of Round 1. (3) Round 3: Reaching consensus and establishing relationships - A structured questionnaire provides controlled feedback to the panel aiming to reach consensus on the research problem and asks them to correlate technologies to sources of brittleness.

The most critical step determining this research's reliability is the criteria set for assembling the panel of experts. The method used to generate the sample is commonly regarded as purposive sampling, which requires applying the participant's knowledge and experience to the problem under investigation. While in most cases, purposive sampling results in the selection of a small sample, which multiple critics might argue lacks representativeness, Akins et al. (2005) demonstrated the stability in results as the sample size grows in a Delphi method. Rowe and Wright (2001) recommend a panel size between 5 to 20 experts, stating that an increase in the panel size does not increase the accuracy of the results. In addition, they state that a combination of

Table 1
Experts' Panel Categories and Specializations.

Expert category	Specializations and areas of expertise
Academia (3)	Transportation and Highway Engineering (3)
Industry (15)	Asset Management (2)
	Highway Engineering (1)
	Independent Consultant (1)
	Railway Construction (1)
	Railway Systems Engineering (2)
	Independent Analyst & Researcher (1)
	Principal Consultant (3)
	Transport Planning (1)
	Transport Engineering (1)
	Traffic Management (1)
	Sustainability Consulting (1)
Management (7)	Highway Management (1)
	ICT Management (1)
	Railway Systems Management (2)
	Innovations Management (1)
	Operations Management (1)
	Project Management (1)
Government (2)	Transport Technology Investment (1)
	Land Public Transport Agency (1)
Non-Profit Organizations (3)	Public Transport Users Association (1)

multiple specialities forms a broader and more holistic view of the problem. As a result, a heterogeneous panel was assembled, as shown in Table 1, comprising of experts from various sectors, namely:

1. Academia - Strong knowledge and background of the current technical problems, research gaps, and emerging technologies.
2. Industry - An engineering background with an understanding of the latest developments in the industry, the barriers faced through both technical and organizational issues.
3. Management - A strong background in the economic and organizational direction of the industry.
4. Government - Decision-makers driving the adoption/hindering of new technologies in the field, as well as, developers of policies and transportation plans.
5. Non-Profit Organizations - Strong influencers on the government's policies and their adoption/hindering of new technologies in transportation.

The panel members were, hence, chosen based on their years of experience and areas of speciality. The experts chosen needed to be in a solid position to judge the deficiencies in the system and the possible technologies to tackle them. Access to such information was made convenient through a professional social media platform called Linkedin. This was the main gate through which the researchers acquired information regarding the background and suitability of potential experts and initiated contact to propose participation in the research. Invitations were sent to a large selection of experts in pursuit of achieving a balance between the different expert categories, however, given the timeline and commitment required of participants, only 30 experts agreed to participate in the Delphi rounds. Nevertheless, the sample size of 30 experts falls within the ideal number of a Delphi approach. Satisfying the importance of having a solid background in the field, 93% of the experts chosen possessed an experience of greater than ten years long. Additionally, a self-assessment was included, which required the experts to identify their level of familiarity with the research topics.

The measure of consensus must be determined prior to data acquisition to strengthen the methodology's rigour. The nature of the Delphi research where controlled feedback is provided on preceding rounds causes the experts' opinions to converge over a few iterations. There is no agreement in the literature regarding the optimum number of rounds, yet a common recommendation is to iterate until the responses stabilize (Rowe and Wright, 2001). A frequently used measurement index is the interquartile range (IQR). The IQR is a function of statistical dispersion which embodies the central 50% of observations, calculated as the difference between the 75th percentile and the 25th percentile. The recommended adequate range of judging the panel's consensus based on the interquartile range is an IQR value of less than 1 (IQR $\leq$ 1). This is particularly more accurate as a consensus indicator on scales of 4 to 5 points (von der Gracht, 2012). A modification to the Delphi method was performed for the third round of the study. The experts were given the choice to either agree or disagree with the collective result of the preceding round, and were asked to defend their position in case of disagreement. This strategy was adopted to counteract the possibility of an artificial consensus where experts are forced to agree, hence, stifling invaluable argument data.

The first round generated an in-depth view of the current local situation of Klang Valley's transport system. The research method was flexible to accommodate the geographical and time limitations of the interviewees, offering different interview types, namely, phone calls (26%), face-to-face meetings(30%), online meetings using Skype for Business platform(7%), and lastly, emailed questionnaires(37%). The interviews were semi-structured and ranged from 30 to 60 min. After each interviewee's consent, the interviews were recorded using a smartphone solely to retrieve data.

A qualitative analysis of the interviews was conducted which resulted in (1) a list of prominent and emerging technologies in the region, (2) a list of stresses and barriers weakening the system, and (3) a list of possible improvements to the system. Firstly, a list of 95 technologies were extracted from the interviews. This list was reduced to a final list of 23 technologies through the following steps:

- Any duplicate items in the list were eliminated.
- Closely related items were grouped together under more general terms. For example, grouping "Intelligent traffic systems", "intelligent traffic signal control", "VMS systems", etc., under "Intelligent Transport Systems". Such grouping was done based on the terms' definitions in the literature.
- A count of any duplicate items was performed prior to deletion in order to gauge whether this item should be grouped under a general term or presented on its own. For example, "Vehicle detection and collision brake system" can fall under "Intelligent Transport Systems". However, the term had a count of 5 (mentioned by 5 different experts), therefore it was presented as an independent item in the list of technologies. Any item with a count greater than 5 was represented as an independent item in the final list.
- Grouping items of the same meaning. For example, grouping Uber and GRAB under e-hailing ride technologies, or grouping autonomous trains and driverless trains.

The final list of 23 technologies along with their definitions and justification for being part of the list was shared with the experts for their reference while going through the second and third round questionnaires. The table of definitions, as presented to the experts, is attached in Section Appendix A of this paper. This table ensured that the experts had a common understanding of each term prior to evaluating it on a statistical level. However, each item on the list of technologies was evaluated independently and not in comparison to the other items. As a result, there is no room for double-counting which would have been a source of error considering how some terms are closely related. It must also be noted that some of the technologies are not emerging per definition as the experts recommended the importance of evaluating existing prominent technologies alongside emerging technologies.

Round 1 produced a list of 32 Sources of Brittleness, in addition to the list of technologies. Subsequently, the second round used a questionnaire to develop quantitative values for the technologies and sources of brittleness identified. An online-based form was created using Qualtrics platform. The form was distributed through a personal link to each of the experts, enabling the researcher to track the progress and completion rate of the members and send reminders when necessary.

Table 2
Central Tendency Analysis of the Sources of Brittleness (SBs).

Priority			Severity		
Rank	Source of Brittleness	*P*	Rank	Source of Brittleness	*S*
1)	Weak political will	4.29	1)	Weak political will	4.33
2)	Lack of system integration and standardization	4.27	2)	Congestion	4.20
3)	Congestion	4.26	3)	Poor connectivity, first mile and last mile connectivity	4.19
4)	Poor connectivity, first mile and last mile connectivity	4.19	4)	People's mindset	3.96
5)	People's mindset	4.04	5)	High private car ownership	3.96
6)	Weak enforcement	3.96	6)	Conflicting government policies	3.93
7)	Quality of bus services, unreliable bus schedules	3.89	7)	Unorganized urban and infrastructure planning	3.85
8)	Conflicting government policies	3.89	8)	Lack of system integration and standardization	3.81
9)	Unorganized urban and infrastructure planning	3.81	9)	Weak enforcement	3.78
10)	Funding of railway projects	3.78	10)	Quality of bus services, unreliable bus schedules	3.78
11)	Capacity of the existing infrastructure	3.73	11)	Road safety	3.78
12)	Rate of urbanization	3.70	12)	Lack of maintenance	3.73
13)	High Private Car Ownership	3.67	13)	Funding of railway projects	3.69
14)	Road Safety	3.67	14)	Rate of urbanization	3.56
15)	Lack of awareness and education on new technologies	3.56	15)	Capacity of the existing infrastructure	3.52
16)	Investment in research	3.56	16)	Accuracy of data used in infrastructure planning	3.50
17)	Lack of innovation	3.52	17)	Population growth	3.38
18)	Rate of technology advancement	3.44	18)	Lack of innovation	3.35
19)	Cost effectiveness of new technologies	3.42	19)	Fragmented industry structure	3.30
20)	Imbalance and shortages of skills	3.42	20)	Climate change, pollution, and vehicle emissions	3.26
21)	Fragmented industry structure	3.40	21)	Rate of technology advancement	3.26
22)	Lack of maintenance	3.38	22)	Cyber security	3.26
23)	Lack of inclusivity	3.33	23)	Investment in research	3.22
24)	Ageing infrastructure	3.31	24)	Cost effectiveness of new technologies	3.21
25)	Accuracy of data used in infrastructure planning	3.31	25)	Imbalance and shortages of skills	3.21
26)	Climate change, pollution, and vehicle emissions	3.26	26)	Low price of petrol	3.17
27)	Population growth	3.26	27)	Lack of awareness and education on new technologies	3.13
28)	Cyber security	3.19	28)	Lack of inclusivity	3.11
29)	Low price of petrol	3.04	29)	Ageing infrastructure	2.87
30)	Use of non-local technologies	2.93	30)	Use of non-local technologies	2.81
31)	Ageing population	2.81	31)	Ageing population	2.74
32)	Electricity demand of existing technologies	2.70	32)	Electricity demand of existing technologies	2.72

The method yielded a 100% response rate with all experts completing this round's questionnaire. For the third round, the same research method of Round 2 was employed. A structured questionnaire was divided into 5 sections. The first three sections introduced the top 10 SBs and technologies based on the previous round mean rating and required the experts to re-rate the items which did not achieve consensus. However, in this round, the experts were required to defend their position if they were to rate an item outside the consensus range. This strategy was taken up to explore the rationale behind each member's choice and develop an understanding beyond consensus. The method yielded a 93% response rate, with 28 experts completing this round's questionnaire. A summary of the rounds is presented in Fig. 3.

Table 3
Central Tendency Analysis of Technologies.

Impact on System Resilience			Feasibility		
Rank	Technology	*IMP*	Rank	Technology	*F*
1)	Intelligent Transport Systems	2.70	1)	E-hailing ride technologies	1.73
2)	Big Data Analysis	2.63	2)	Intelligent Transport Systems	1.59
3)	Smart Buses and Bus Stops	2.59	3)	Big Data Analysis	1.56
4)	Artificial Intelligence	2.46	4)	Building Information Modelling	1.56
5)	E-hailing ride technologies	2.27	5)	Smart signalling systems (CMMS, SCADA, etc.)	1.44
6)	Circular Railway Line	2.27	6)	Alternative fuel vehicles	1.41
7)	Smart signalling systems (CMMS, SCADA, etc.)	2.26	7)	Smart Buses and Bus Stops	1.30
8)	Autonomous Trains	2.24	8)	Modular Construction	1.28
9)	Crowd-sourcing information	2.21	9)	Solar Energy	1.26
10)	Modular Construction	2.19	10)	Artificial Intelligence	1.23
11)	Trackless Trams	2.11	11)	Autonomous Trains	1.20
12)	Alternative fuel vehicles	2.07	12)	Virtual Reality	1.16
13)	Building Information Modelling	2.07	13)	Vehicle detection and collision brake system	1.15
14)	Next-gen GPS	1.96	14)	Crowd-sourcing information	1.04
15)	Vehicle detection and collision brake system	1.96	15)	Circular Railway Line	1.00
16)	Vehicle-to-everything (V2X) communication	1.85	16)	Next-gen GPS	0.92
17)	Truck Platooning	1.81	17)	Vehicle-to-everything (V2X) communication	0.85
18)	Solar Energy	1.78	18)	Blockchain	0.68
19)	Hyperloop technology and High-Speed Rail	1.70	19)	Trackless Trams	0.59
20)	Virtual Reality	1.67	20)	Truck Platooning	0.48
21)	Blockchain	1.65	21)	Air Taxis	0.44
22)	Autonomous Cars	1.62	22)	Hyperloop technology and High-Speed Rail	0.42
23)	Air Taxis	1.37	23)	Autonomous Cars	0.42

4. Results & discussion

This section will chronologically display the results and analysis, beginning with the first stage, where ideas were brainstormed, and leading to the final research outcomes.

4.1. Brainstorming

The main aim of this stage was to brainstorm the main items from which the framework results are derived, which are a list of technologies and a list of Sources of Brittleness. Thematic analysis was found to be the best-suited approach for the data of Round 1. Although initially, a deductive approach was chosen to analyse the interview transcripts where the themes were mainly split into Sources of Brittleness and Technologies, the depth of information in the transcripts led to a more inductive approach to document all the valuable details expressed by the experts. After transcribing the interviews and importing the scripts into

Table 4
Improvements listed in descending order of potential impact and feasibility.

Rank	Improvement	%	
1	A transportation master plan which considers a time concept such as the 45-minute city	85.19%	
2	Mobility-as-a-Service journey planner solution	74.07%	
3	Standardize all existing railway systems to enable integration and enhance compatibility	74.07%	
4	Increase the number of public transport stations in the outskirts	70.37%	
5	Connect the railway system in real-time to Google Maps	70.37%	Very High Potential (70%)
6	Dedicated BRT lanes	66.67%	
7	Congestion charges	62.96%	
8	Have an independent body to oversee public transportation	62.96%	High Potential (60%)
9	Increase capacity by increasing the rolling stock and reducing the waiting time	59.26%	
10	Government contributes to the CapEx and OpEx of the public transport	59.26%	
11	Employer transportation subsidies	55.56%	
12	Invest in research and development	55.56%	
13	Setting specific goals such us "All vehicles on the road must be diesel free by 2035"	55.56%	
14	Make e-hailing options cheaper to resolve last mile connectivity	55.56%	
15	Incentivize the use of sustainable transport through a new TNC	51.85%	Moderate Potential (50%)
16	An underground system round the CBD area	48.15%	
17	Collect data for the next few years on information such as air quality, travel behaviour, etc.	48.15%	
18	Cheaper train ticket if you park at the station	44.44%	
19	Focusing the modal shift from private to public transportation on expats	44.44%	
20	A tool showing current land use as well as projected development for operators'use	44.44%	
21	Test policies in the market before enforcing them (closed-loop)	44.44%	
22	Zone charges	40.74%	
23	Introduce more monorail systems	37.04%	
24	Provide more parking provisions for motorbikes or cycles	33.33%	
25	Installing charging stations	29.63%	
26	Emission free zones	25.93%	
27	Increasing petrol price	25.93%	
28	Ventilated bus stops	18.52%	
29	Miniloop (elevated, covered and ventilated bicycle highway)	14.81%	
30	Re-introduce private taxi business model	7.41%	Low Potential (50%)

NVivo, 3 main themes were generated: 1) Technologies, under which we concluded a final reduced list of 23 technologies, 2) Sources of Brittleness, with a final list of 32 SBs, 3) Improvements, a reduced list of 30 suggested improvement ideas to the system which did not fit under the technologies theme. Among these technologies is Intelligent Transport Systems, which are best described as ICT devices or systems that enable the collection, processing and exchange of information, such as traffic data, flow conditions, and accidents, between service providers of traffic and transport infrastructure users (Janušová and Čičmancová, 2016). In addition, it is important to note that technologies with the same purpose were grouped to produce the reduced list. For instance, Hyperloop and High-Speed Rail were both suggested by the experts as a technology for reducing travel time.

4.2. Analysis

4.2.1. Central tendency

The main aim of this stage was to develop quantitative values and insights for the data extracted during the first stage. As explained in the methodology section, the data is analysed twice for consensus and central tendency. The results of the analysis from Round 2 is given to the experts as feedback to achieve consensus. The final central tendency value for each of the Sources of Brittleness Priority, P, and Severity, S, attributes is presented in Table 2. *Priority* was defined as a measure of the level of urgency to tackle the SB. *Severity* was defined as a measure of the disruption to system resilience as a consequence of the SB. Both Priority and Severity were rated on a 5-point scale, with 1 being the lowest priority/severity and 5 being the highest.

The final central tendency value for each of the Technologies potential Impact on resilience, IMP, and Feasibility, F, attributes is presented in Table 3. *Impact* was defined as the measure of how each technology impacts the four determinants of resilience (Robustness, Redundancy, Resourcefulness, Rapidity). This was measured on a scale of 0 - Has no potential contribution, 1 - Has minimal potential contribution (unlikely to have much effect), 2 - Has considerable potential contribution (Likely to be utilized in different ways to enhance the system with aid of other technologies), 3 - Has high potential contribution (Likely to achieve maximum requirements of the system independently). Feasibility was judged based on the technology's status with regards to cost, ease of implementation, high awareness, and existing supportive governance in the Klang Valley region. This was measured on a scale of -1 - Infeasible (Unlikely to be adopted due to multiple barriers, e.g. very high cost, complete lack of awareness and expertise, etc.), 0 - Neutral (Faces standard barriers e.g. average cost, neutral governance), 1 - Feasible (Likely to be adopted due to minimal barriers, e.g low cost, supportive governance, high awareness), 2 - Very Feasible (Already being adopted in Klang Valley).

Table 5
Relational Factor Questionnaire Raw Data.

Technology	Congestion	Weak Political Will	Lack of System Integration and Standardization	High Private Car Ownership	Poor Connectivity, first and last mile
Intelligent Transport Systems	18	6	19	8	14
Big Data Analysis	15	5	21	5	9
Smart Buses and Bus Stops	13	11	15	11	19
Artificial Intelligence	9	2	22	3	9
E-hailing ride technologies	14	8	7	18	10
Intelligent Asset Management and maintenance	4	5	18	1	2
Autonomous Trains	14	8	11	11	8
Building Information Modelling	1	9	18	1	0
Crowd-sourcing of transit information and performance metrics	17	6	13	8	13
Circular Railway Line	15	10	13	11	14
Modular Construction	2	8	15	1	2
Virtual Reality	4	5	14	2	3

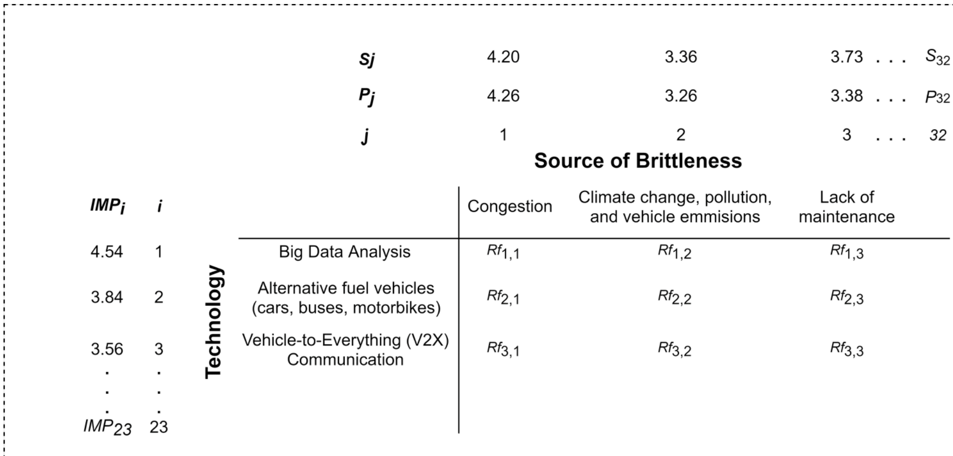

Fig. 4. Relational Factor matrix assembly example guide **(MATRIX A)**.

4.2.2. Improvements

For the list of Improvements extracted from the thematic analysis, a nominal question was formulated to identify ideas of high significance considering the current situation. Table 4 shows the improvements in descending order of votes. The % column indicates the percentage of experts who regarded the item of positive potential effect on the system's resilience.

4.3. Relationship formulation

While performing a linear regression is common in data analysis, this research takes a unique approach to develop a resilience assessment relationship with regression. From the brainstorming round, 23 technologies and 32 SBs were concluded from the qualitative analysis of the data. To develop a relationship between the technologies and SBs, the third round requested the experts to choose the technologies with the potential of eliminating an SB. This was limited to 5 central SBs: Congestion, Weak Political Will, Lack of System Integration and Standardization, High Private Car Ownership, and Poor Connectivity, first and last mile. These were explored against 12 technologies as shown in Table 5. The values represent the number of experts who voted for the technology as a solution to the corresponding SB.

Unfortunately, it was impractical to develop a full matrix of 23 technologies against 32 SBs. Therefore, a prediction model was built, using Multiple Linear Regression, to develop a Relational factor (*Rf*) matrix encompassing all technologies and SBs. The model was built from the raw data in Table 5. The results in this table were set as the dependent variable in SPSS and analysed against Priority (*P*), Severity (*S*), Impact on resilience (*IMP*), and Feasibility (*F*) as independent variables. The model was checked to adhere to the assumptions of Multiple Linear Regression of multicollinearity and homoscedasticity. On the first run, the variables statistically significantly predicted $Rf, F(4,55) = 11.006, p = .000, R^2 = .445$. However, only the variables Priority ($p = .000$), Severity ($p = .000$), and Impact on Resilience ($p = .000$) added statistically significantly to the prediction of Rf. There was no significant addition to the prediction by the Feasibility variable ($p = .166$). On the second run, the Feasibility variable was eliminated and the model statistically significantly predicted Rf, $F(3,56) = 13.780, p = .000, R^2 = .425$. The three variables Priority ($p = .000$), Severity ($p = .000$), and Impact on Resilience ($p = .001$) added statistically significantly to the prediction of Rf. The final model is represented by Eq. (1).

$$\text{predicted } Rf = 4.233 + (11.061 \times P) - (15.990 \times S) + (6.110 \times \text{IMP}) \tag{1}$$

Subsequently, a holistic matrix encompassing all technologies and SBs was developed where the technologies and SBs were numbered to give each a unique ID. For each technology, numbered $i = 1 \cdots 23$; the relational factor, Rf, was calculated corresponding to each SB, numbered $j = 1 \cdots 32$. This was calculated through Eq. (2). An example of the matrix assembled in Microsoft Excel is demonstrated in Fig. 4 showing the first three Technologies and Sources of Brittleness.

$$Rf_{i,j} = 4.233 + \left(11.061 \times P_j\right) - \left(15.990 \times S_j\right) + \left(6.110 \times IMP_i\right) \tag{2}$$

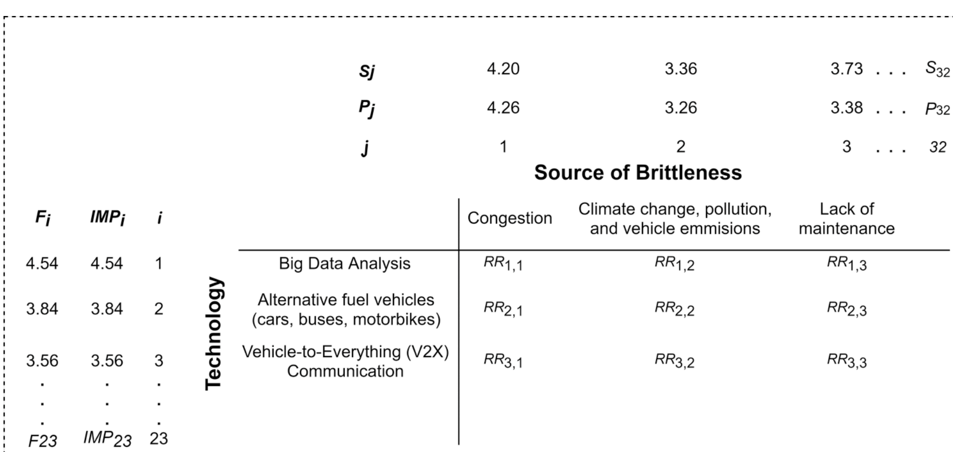

Fig. 5. Relative Resilience matrix assembly example guide **(MATRIX B)**.

		S_j	4.20	3.36	. . .	2.81	
		P_j	4.26	3.26	. . .	2.93	
		j	1	2	. . .	32	
F_i	IMP_i	i					**Bulk Relative Resistance**
4.54	4.54	1	$RR_{1,1}$	$RR_{1,2}$	. . .	$RR_{1,32}$	$RR_{bulk,1}$
4.26	3.84	2	$RR_{2,1}$	$RR_{2,2}$	. . .	$RR_{2,32}$	$RR_{bulk,2}$
3.56	3.56	3	$RR_{3,1}$	$RR_{3,2}$	. . .	$RR_{3,32}$	$RR_{bulk,3}$
.	.	.					.
$F23$	IMP_{23}	23					$RR_{bulk,23}$

Fig. 6. Bulk Relative Resilience summation example guide.

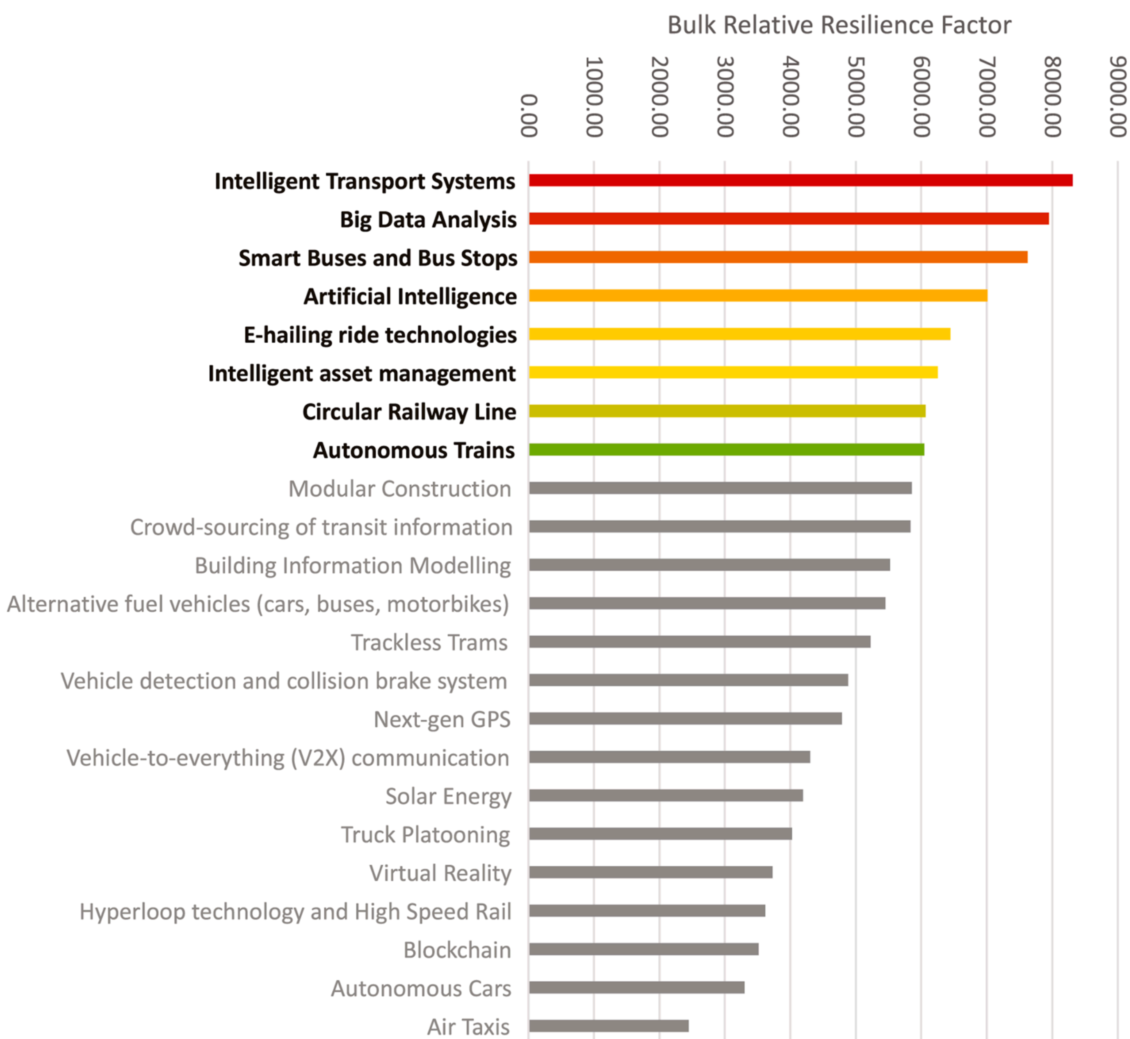

Fig. 7. List of Top Recommended Technologies and their corresponding Bulk Relative Resilience Factor.

The next step was to evaluate the relative resilience of the system when one of the technologies was independently employed. The Relational factor, evaluated in the previous section, provides a measure of how effective a specific technology is in mitigating an existing Source of Brittleness. As per REBET's assumptions, the more problems a technology can effectively solve, the better it is for the system's resilience. Captivating the entire framework of this research, a simple relationship was developed for evaluating Relative Resilience, RR, as expressed in Eq. (3).

$$RR_{i,j} = Rf_{i,j} \times \left(P_j + S_j + IMP_i + F_i\right) \tag{3}$$

Where $RR_{i,j}$ is the Relative Resilience achieved by a technology i against a Source of Brittleness j, $Rf_{i,j}$ is the relational factor corresponding to the technology and SB being evaluated, P_j is the mean priority of the SB, S_j is the mean Severity of the SB, IMP_i is the mean Impact on Resilience of the Technology, and F_i is the mean Feasibility of the technology.

The value of $Rf_{i,j}$ is retrieved from the matrix assembled in the previous section. To ease the calculation, another matrix was assembled for the calculation of $RR_{i,j}$ as shown in Fig. 5. The final step was to develop a measure that aggregates a specific technology's total contribution to resilience. This would precipitate a meter upon which each technology stands in comparison to each other. Accordingly, the Relative Resilience values, RR, for a single technology corresponding to all 32 SBs was summed up to produce a Bulk Relative Resilience figure, RR_{Bulk}, for each technology, where the value for the first technology $i = 1$ is expressed in Eq. (4). Using the results from Matrix B of Relative Resilience, the RR_{Bulk} value for each technology was calculated by summing the rows of the matrix. To clarify, an illustration is shown in Fig. 6. The score of each technology was then compared and the technologies were arranged in descending order. The top 8 technologies, as shown in Fig. 7, are the most highly recommended for investment and research to achieve system resilience in the Klang Valley region.

$$RR_{Bulk,1} = \sum_{j=1}^{j=32} RR_{1,j} \tag{4}$$

5. Conclusion

5.1. Summary

This research contributes academically and practically in reducing the technological uncertainty within the realm of transportation by prioritizing a shift towards resilience. The developed research framework bridges the gap with respect to resilience assessment and emerging technologies by linking these technologies to weaknesses within the system and identifying the technologies with the highest impact on the resilience of the system. The research offers a comprehensive approach that allows resilience to be embedded in the development and planning of transportation systems by utilizing emerging technologies as a future proofing mechanism. To achieve the final connection between resilience and technologies, the first objective of the framework was to pinpoint the critical sources of brittleness within the system. These are chronic stresses and problems that cause the transportation network to be vulnerable and prone to major failures under unanticipated situations. 32 sources of brittleness were identified during the interview rounds. These were investigated for their level of Priority and Severity. 12 out of the 32 sources were classified under the Social dimension. Therefore, Klang Valley's transport system is made vulnerable mainly due to its social brittleness.

To counter the sources of brittleness in the system, the framework's second objective was to identify the most relevant technologies to Klang Valley's system and define their potential based on their degree of feasibility and impact on resilience, through the collective intelligence of the experts' panel. 23 technologies were successfully selected and analysed. The final list of technologies is derived through a statistically meticulous process to meet the third and fourth objectives of the research. A multiple linear regression model was first defined which served as a prediction model of the relationship between any SB-technology pair. The model predicts the relationship based on the attributes of the source: Priority and Severity, as well as the technology's impact on resilience. Subsequently, each technology is valued by its relative resilience factor on the system. This is calculated based on the relational factor, the SB's priority and severity values, and the technology's feasibility and impact values. The presented list of technologies, shown in Fig. 7, highlights the technologies with the highest contribution to Klang Valley's transport system resilience. The comparison and the ranking of these technologies offer a data-driven basis upon which future research, investments, and transport policies, can move forward while ensuring system resilience is at the forefront.

Another crucial finding, which was not part of the initial research focus, is the significance of complementary improvements and system changes that must accompany the applications of emerging technologies in order to be effective. Through this research, the two improvements most needed for the Klang Valley region were 1) A transportation master plan which considers the emerging technologies, 2) A mobility-as-a-service solution which integrates all public transit and non-ownership modes. Lastly, it was noted that the introduction of a technology into the system does not simply ameliorate the situation. Each technology comes with its own threats and change to the dynamics of the system. A main example is the institution of autonomous cars. Multiple experts disagreed on whether introducing this technology would worsen the congestion on the road by offering a service to people who were previously unable to conveniently commute. Therefore, prior to instituting any technology, a careful inspection of its risks must be assessed preparing a counter plan to mitigate each risk.

5.2. Implications, limitations, and reproducibility

Building on previous literature, the framework developed in this study complements the existing theories of system brittleness. While resilience engineering is heavily focused on high risk, low probability events, it has been emphasized by Woods (2007) and Jackson (2010) that diagnosing and mitigating brittleness in the system enhances the overall reliability of the system, hence, directly strengthening its resilience. Following the definition of Saurin and Carim Junior (2012) on Sources of Brittleness (SBs), this study presented a new approach to detecting the SBs in the system as well as a milestone on how to counter them. In addition to the previous theory of Bruneau et al. (2003) on the four dimensions of resilience (Technical, Organizational, Social, and Economic) being commonly applied to Sources of Resilience in a system, this research framework shifted the common application to Sources of Brittleness, explaining that both sources can be classified in a similar manner.

Furthermore, the framework provides a new insight on the relationship between technologies and resilience, offering a new technique on assessing relative system resilience based on the employed technology. Not only does this open a new door to exploring technology effects on resilience, but also aids in refining infrastructure management strategies by encouraging the incorporation of emerging technologies. The resulting list of prioritized technologies can be taken into account when considering which technologies are of the highest potential in enhancing system resilience. Researchers should shift their focus on these technologies when exploring system resilience in the Klang Valley region.

The rigour of this framework has been justified throughout the chapters of this thesis, yet there exist a few imperfections which should be noted for future applications. Beginning with the assembly of the experts' panel, the strict criteria on selecting the experts led to high quality results and research procedure. The interest of the chosen experts in the topic yielded a high response rate for all rounds. However, the categories should be balanced for future investigations to enable a thorough analysis of variance between group opinions. In addition, it is recommended to include sociologists and economists as part of the panel who can provide a better outlook on the Social and Economic dimensions. It must also be acknowledged that due to the lack of participation from technology service providers, the results of this research present only half of the picture. The results demonstrate technology from the perspective of transportation experts, lacking any insight on the perspective of technology experts on transportation. This is an important limitation that can be tackled through future research into the topic.

The sample size of 30 experts has proven to be a reliable number throughout the research method. During the interview stages, multiple new ideas are brainstormed by the first few experts. These ideas began to repeat themselves with every additional expert, producing fewer new suggestions. Furthermore, the greater the number, the more complex the issue of data marshalling becomes and the longer the time required for completing the analysis between stages, hence, increasing the time commitment required by the experts which can lead to a drop in response rate. In addition, it must be noted that the 30 experts were an adequate representation of Klang Valley, which might not be the case for future applications of the framework with a wider geographic scope.

The temporal factor plays a critical role in the reproducibility of the final result of this study. The technologies brainstormed within the initial stages can be overtaken by others within a short period of time due to the fast rate of technology advancement. While the sources of brittleness might remain in the system for longer, the results might still change over time. Furthermore, the geographical factor is a core component of this framework upon which the results are based. Therefore, any change in the geographical location will produce different results.

Another governing factor of the success and rigour of this framework is the knowledge and attitude of the researcher. In the initial stages, the researcher must adhere to a strict criterion when selecting the experts as this framework values quality over quantity. Moreover, the attitude and public relations skill of the researcher controls the response rate in each stage. While successfully producing the intended result of a recommended technology list for resilience, it is important to point out some of the model's limitations. The predicted Relational factor model produced by Multiple Linear Regression showed that the model only accounts for 43% of the variance. This might precipitate a significant level of inaccuracy in the final list since 57% of the relationship is unknown. To build the model, only 12 technologies were tested against 5 sources of brittleness. As a result, it is suggested that for future implementations of the framework, more data should be collected to build a higher level of accuracy.

5.3. Future recommendations

Being an incipient field of research within Malaysia, there is a lot more to be explored. Considering the timing of this research having been conducted during the world pandemic of the Coronavirus disease, Malaysia's strengths and weaknesses surfaced during its fight against this outbreak. One of the notable sources of brittleness affected the food supply chain due to the restrictions on movement and transportation. As the scope of this research focused on passenger transport only and did not look into freight transportation, it is highly recommended to consider the resilience and sources of brittleness of freight transport for protection and rapid recovery from similar future uncertainties.

Regarding the framework design, it is undeniable that the relationship upon which the framework is based heavily relies on expert opinion. Although this offers a unique approach to the solution which domesticates the data, future research can incorporate mathematically calculated attributes as well as historic data to both technologies and sources of brittleness. Examples of such could be duration since the institution of a technology within the country, cost estimates of adopting the technology in the system, or a direct relation between technologies and the four determinants of resilience. Furthermore, it can also be observed that the developed framework only evaluates the benefits of one technology at a time. In future applications, different combinations of technologies can be investigated, perhaps through an operations research method.

Moreover, in addition to the main objectives of this research, the qualitative analysis provided evidence that emerging technologies come with certain side effects. Based on this insight, future research is needed to determine the threats of the technologies to the system, possibly through a SWOT analysis of each technology. Lastly, the framework heavily focuses on producing technology recommendations through the comparison of their effects on the system. Yet, the framework gathers commensurate data regarding the Sources of Brittleness in the system. It is recommended that the framework is taken a step further to measure the degree of overall brittleness in the system.

It is undeniable that resilience of a system has become a top priority, considering the exacerbating damage that a sudden event, such as the most recent pandemic, can cause. Research and investment must begin to shift their focus towards resilience. It is the responsibility of the upcoming research to push the surrounding systems towards a state of reliability to avoid severe future damages caused by unforeseen circumstances.

CRediT authorship contribution statement

Shams Ghazy: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Visualization. **Yu Hoe Tang:** Supervision, Writing – review & editing, Conceptualization, Validation. **Kevin Luwemba Mugumya:** Writing – review & editing, Formal analysis, Visualization. **Jing Ying Wong:** Writing – review & editing, Supervision. **Andy Chan:** Resources, Supervision.

Declaration of Competing Interest

None

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Appendix A

Table A.1.

Table A.1
List of technologies and their definitions and/or justification for being included in the technologies' list as presented to the experts.

No.	Technology	Function and justification
1	Big Data Analytics	The extraction of patterns, behaviors, and correlations from large, often heterogenous data sets using advanced analytic techniques.
2	Alternative fuel vehicles (cars, buses, motorbikes)	An umbrella term for any vehicle that relies on a fuel other than petroleum e.g. hydrogen powered, electric, hybrid, etc.
3	Vehicle-to-everything (V2X) communication	An item which represents the communication between vehicles and other entities such as infrastructure, grids, smart devices, and even other vehicles.
4	Intelligent asset management using smart signaling systems, computer maintenance management system (CMMS), SCADA, etc.	Particularly represents the technologies employed in state-of-the-art maintenance management which gather real time data and produce maintenance orders accordingly.
5	E-hailing ride technologies	A technology which allows users to book rides through their devices. This includes cars, motorbikes, etc.
6	Solar Energy	Considering the high reliance of Malaysia on non-renewable sources of energy, which inhibits the adoption of electric cars, proposing solar energy as an alternative was included here despite not being a emerging transport technology.
7	Hyperloop technology and High-Speed Rail	This item represents rail transport technologies which possess a significantly higher speed than traditional railways.
8	Blockchain	A rising technology in cyber security services, blockchain can protect digital assets through unaltered, transparent history.
9	Modular Construction	A term for different off-site construction techniques including precast technologies, volumetric construction, and hybrid techniques.
10	Intelligent Transport Systems	A wide term which covers different traffic management systems including car navigation, speed recognition, VMS technologies, and traffic signal control systems.
11	Smart Buses and Bus Stops	State-of-the-art buses and bus stops with effective communication systems.
12	Trackless Trams	A new train technology which operates without tracks.
13	Air Taxis	A small commercial aircraft which can be booked for short duration flights.
14	Autonomous Cars	A car which operates without the need for human input through communicating with its surroundings.
15	Circular Railway Line	Although this is not characteristically a technology, it was evaluated as one instead of an idea for improvement due to its high frequency suggestions as an optimum solution.
16	Autonomous Trains	Driverless trains which operate without human involvement. This was separated from autonomous vehicles as it represents public transport.
17	Building Information Modelling	A digital documentation of all physical as well as functional elements of an asset.
18	Virtual Reality	A three-dimensional simulation which allows human exploration and interaction with the virtual environment.
19	Next-gen GPS	The latest Global Positioning System (GPS) technologies which are anticipated to be three times more accurate with powerful signals.
20	Artificial Intelligence	Programming machines to think like humans has recently invaded the transport industry through its potential applications in autonomous cars, maintenance systems, and more.
21	Truck Platooning	Although this technology falls under V2X, it was separated in order to investigate whether freight transport is in high demand of a solution.
22	Crowdsourcing of transit information and performance metrics	Gathering information regarding transit systems from users.
23	Vehicle detection and collision brake system	A technology which uses vehicle communication to enhance road safety. Although this is covered by ITS, it was separated for investigating a narrower focus on road safety.

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