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Application of Catastrophe Theory to Assess Transport Sector Vulnerability using Macro-Environment Factors – A Case of Floods in the Perlis State of Malaysia

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A B S T R A C T

Decision-makers must possess rapid assessment tools to evaluate the vulnerability of the transport sector in light of the disaster-support function. Earlier vulnerability assessment models were often prone to subjectivity in quantifying and determining transport vulnerabilities. The present paper examines the macro-environment to select factors affecting transport sector vulnerabilities. A total of 30 criteria and indicators are chosen within five factors, namely Social, Technological, Environmental, Economic and Political (STEEP), to assess the macro-level vulnerability assessment taking the flood-prone State of Perlis in Malaysia as a case study. Owing to the inherent advantages of eliminating subjective and qualitative aspects, catastrophe theory is applied to obtain multiple assessment indices defining vulnerabilities and relative importance. The results obtained using the catastrophe assessment system based on STEEP factors reveal high transport vulnerability values for social factors, followed by economic, political, environmental and technical factors. Results show that among the social factors, gender, age, and income play a significant role in defining vulnerability. Other than social factors affecting transport vulnerability, the economic condition of the state, land use distribution, political attitude and the role of civic society were also found to have significant influence. Findings suggest that the immobility of the mass population and the unavailability of sufficient infrastructure and technology are the major factors of high vulnerability. The present research urges the policymakers to focus on areas such as transport systems more usable for the elderly, promoting gender equality in the transport sector and planning better transport accessibility, particularly for low-income population, that can help to improve their effective mobility and make transport system more affordable to all. The developed assessment model is simple and operational, giving decision-makers an alternative approach to assess transport vulnerabilities.

1. INTRODUCTION

The 17 Sustainable Development Goals (SDG), with their 169 targets, were adopted by all United Nations Member States in 2015 for inclusive and equitable development, leaving no one behind by 2030. The SDG aims are broad, interlinked, and across various development sectors. Sustainable transport pushes sustainable development through its interlinking impacts on nearly all the SDGs. Sustainable transport for all should be the prime agenda for policymakers. Transport brings a substantial share to the national Gross Domestic Product (GDP) in most countries across the world (European Commission, 2011; World Bank, 2014; Shahid and Minhans, 2016). As transport provides the links in a complex network of relationships between producers and consumers, any disruption of the transport sector accounts for economic losses and public suffering.

Vulnerability assessment is the first step of adaptation and mitigation planning. Therefore, it is necessary to assess the vulnerability of the transport sector to natural disasters in order to improve resilience to natural hazards. Most of the methodologies developed to assess transport vulnerability are either computationally intensive or applicable only within small networks. Furthermore, as there is no unique definition or concept of vulnerability assessment in general, the assessments are thus widely prone to subjectivity, and hence the outcomes are often debatable. Applying the principles of catastrophe theory for assessment and monitoring has demonstrated that subjectivity can be largely eliminated through selective criteria and indicators (Wang et al., 2014a; Wang et al., 2014b). Catastrophe theory employs an exhaustive categorisation and standardisation technique that combines a set of defined attributes with different weights into a single vulnerability index. Such methodologies can be extended in principle to include further attributes of a subjective nature to reflect a wider set of vulnerability-related issues in data deficient regions (Ahmed et al., 2014; Wang et al., 2014a; Al-Abadi and Shahid, 2015). Such models' outcomes can significantly help revealing the key thrust areas and broader transport policy level amendments that can be instigated.

Catastrophe theory has been successfully applied in different fields of social and natural sciences (Ahmed et al., 2014), most notably in risk assessments (Balica et al., 2012), occasional congestion control (Xu et al., 2021), environmental impact assessments (Al-Abadi et al., 2016) and ecological security (Su et al., 2011). It has been constantly developed since its derivation in successfully assessing the 'risks' and 'vulnerability' of urban systems (Hsieh, 2014; Poston and Stewart, 2013).

The primary objective of the present study is to propose a method to quantify the vulnerability of the transport sector through a set of macro-environmental factors that are mainly static and uncontrollable in the short term. The catastrophe theory is used to draw the relative importance of factors, criteria, and indicators used in the study (Ahmed et al., 2014). The proposed method is applied to assess the vulnerability of the transport sector to floods in the state of Perlis in Malaysia. A large part of the Perlis state is low-lying and flood-prone. The frequent floods have inundated large parts of the Perlis, resulting in huge economic losses (Koridor Utara Malaysia, 2013). The state-level published and publicly available statistical data are used for this purpose. In cases where quantitative data are non-existent, a qualitative approach is used to estimate values. It is expected that the comprehensive description presented in the paper will help researchers and policy planners identify the overall vulnerability of the transport sector and areas that require improvement and see how improvements in one area are linked to the reduction of overall transport sector vulnerabilities. The present paper describes the process, criteria and indicators for assessing transport vulnerability. The study also suggests a practical model and its reckoning procedures, taking the flood-prone State of Perlis in Malaysia as a case study.

This paper has been divided into six sections. Section 2 focuses on models, tools, and factors related to transport vulnerability assessment. Section 3 highlights the methodology followed in this paper. Section 4 focuses on the details of the study area. Section 5 focuses on the results of the analysis and discussion. Finally, section 6 suggests the broader findings and policy implications; in the end, limitations and further scope of research are presented.

2. THEORY AND METHODOLOGY

2.1. Vulnerability assessment of transport sector

Transport infrastructure is considered by some authors as one of the essential lifeline systems, mainly because its damage inhibits interventions in housing and other lifeline systems (Caiado et al., 2012). Due to the extensiveness of transport system elements, it is also more vulnerable to the impact of disasters. Thus, the analysis of transport sector vulnerability, as a whole, is fundamental in planning, construction, and management. A variety of approaches have been developed to assess transport-related vulnerabilities. The first line of research has proposed frameworks for vulnerability assessment (Chen et al., 2007; Jenelius et al., 2006; Qiang and Nagurney, 2008; Sullivan, 2011; Taylor and Susilawati, 2012). The second line of research deals with modelling using quantitative and qualitative methods of vulnerability assessments (Erath et al., 2009; Knoop et al., 2008; Luathep et al., 2011). The third line of research emanates from scenario planning and its use in assessing realistic vulnerabilities by the formation of hypothetical situations (Bell et al., 2017; Matisziw and Murray, 2009). However, the fourth line emphasises the vulnerability assessment itself, where several indices are formed and validated (Bono and Gutiérrez, 2011; Dalziell and Nicholson, 2001; Tatano and Tsuchiya, 2008).

A number of tools have been developed to assess the vulnerability of the transport sector to disasters (Iida and Wakabayashi, 1989; Bell and Cassir,

2000; AASHTO, 2002; FTA, 2004; SAIC, 2005; Nagae and Akamatsu, 2007; Chen et al., 2007; Maltinti et al., 2012; Chen and Miller-Hooks, 2011). The tools have been applied successfully to assess vulnerability and identify the mitigation measures in different regions of the world. Iida and Wakabayashi (1989) proposed Minimum Cut Set approaches to assess the vulnerability of road transport to natural hazards. Bell and Cassir (2000) used the game theory approach to identify the most vulnerable network elements. The American Association of State Highway and Transportation Officials (AASHTO) developed a framework to conduct transportation assets vulnerability assessment in the USA to man-made disasters by considering the physical highway transportation assets, such as bridges, tunnels, etc. (AASHTO, 2002). The Federal Transit Administration (FTA, 2004) proposed a vulnerability assessment model giving emphasis on the critical assets to transit systems. SAIC (2005) developed a transport risk assessment methodology based on the components including asset identification, threat assessment, consequence assessment, vulnerability assessment, and countermeasure development. Nagae and Akamatsu (2007) used weighted entropy theory to assess transport vulnerability. Chen et al. (2007) proposed a Monte Carlo simulation for both the demand and supply side of traffic assignment models for the assessment of vulnerability. Maltinti et al. (2012) developed an index for assessing the vulnerability of links of a road network due to natural hazards. Chen and Miller-Hooks (2011) proposed an indicator of recovery capability in intermodal freight transport using a stochastic mixed-integer program.

Being part of critical infrastructure, the vulnerability assessment of transport is vital for the success of other disaster support functions. As the failure of the transport system would account for the failure of other interdependent systems, it is deemed as the most vulnerable system. Transport vulnerability has been approached by researchers broadly in two ways, one that estimates the transport network vulnerabilities, and the other dealing with vulnerabilities of transport infrastructure and operations.

Vulnerability assessments can be viewed in light of the defined processes and quantifiable concepts. Abundant literature on transport vulnerability assessment has mostly focused on road network reliability, using mathematical modelling and optimisation techniques to identify worst-case scenarios or best responses to such scenarios (Jenelius et al., 2006). While a full range of vulnerability assessment approaches would provide a comprehensive understanding involving transport users, operators and organisations are still deficient. From the policy perspective, it is essential to evaluate the vulnerability of the transport sector in light of the disaster-support function. Benefits of vulnerability assessments using macro-environment factors such as STEEP factors, ranging from the simplicity of assessment, modest data requirements, easily adapted to other study areas, comprehensiveness of analysis, ease to operationalise, rapidity of policy-level decisions, to modest cost requirements. Besides, the assessment based on STEEP factors can help obtain useful insights, such as (i) whether the investment in a particular sector of transport would yield greater benefits (Nieminen et al., 2002), (ii) ranking of schemes that can improve the state of development in an environment of tough competition for scarce transport resources, and (iii) compare mutually exclusive sectors of transport and suggest more effective plans to improve the state of development. Due to the dynamic and inseparable nature of the elements that constitute the macro-environment, the vulnerability assessment broadly represents the ground realities. Furthermore, useful insights are provided by the rapid assessment of performance of the transport system in terms of identification, assessment, testing, and refining of alternatives intended to decrease transport- associated vulnerabilities. It is believed that the assessment based on the macro-environmental factors can sufficiently reveal the vulnerabilities in the transport system. The assessment based on such a system can reveal the deficiencies fairly, so priorities can be fixed.

2.2. Use of macro-environment factors

As described by many business and system analysts, macro environment factors are uncontrollable external conditions that are fixed, but impact the operations. These external boundary conditions of the urban systems are useful in vulnerability assessments (Cascetta, 2009; Moselhi et al., 2005). However, such factors are largely out of the control of operators in the short-term. Long-term changes in planning, design, construction, operation, management, production, and marketing are required to change the macro-environment. The use of acronyms such as STEEP (Fleisher and Bensoussan, 2003), PEST, PESTLE (Dcosta, 2011), or combinations thereof (Social, Technological, Environmental, Economic, Political and Legal concerns) (Cadle et al., 2010) (Thomas and Thomas, 2007) (Minhans, 2008) to describe the state of the macro- environment can be made to assess transport sector related vulnerability.

The transport phenomenon is highly governed by socioeconomic and demographic profiles (Stopher and Meyburg, 1975). The demographics of the population dictate the scale and type of transport systems. Social and demographic trends suggest the general preference and requirements for transport services in disasters. Moreover, the social factors can suggest the characteristics of traffic demand i.e., trip length, trip purpose, trip duration, and the intensity of travel. Similarly, for special transport accessibility and mobility needs, information such as gender, foreign language barrier, religious barriers, income disparities, etc., are necessary. Technological macro-environmental factors, such as the quality and quantity of road networks, vehicle technology, etc., can influence the ability of transport operations and organisations. It is essential to assess the state of technological development in transport as it affects accessibility and mobility, safety, environment, and economy of the disaster area.

A holistic approach to assess transport vulnerability can be adopted, in which the national, state and personal economic abilities could be assessed. Usually, they are measured as transport affordability expressed in terms of transport expenditure per person, per vehicle, per vehicle-km, etc. (Minhans, 2008). Where an assessment involving national and state economics involves nation and state expenditure, as well outputs on transport expenditure on transport linked by GDP and State Domestic Product (SDP), the individuals' economy is assessed based on personal transport expenditure usually linked by the household or personal income level. At national or state level, details of economics are broader, such as total transport expenditure on transport, revenues, and subsidies, etc., than at personal levels, where individual mobility budget is linked to mobility. In fact, other indicators such as unemployment rates, foreign exchange rates and global economy indicators are widely used to assess economic states (Benson and Clay, 2004).

The assessment underlines the importance of the physiographic, climatic and built-up environment in influencing traffic and transport operations, especially during disasters. The terrain and geotechnical information such as level, hilly, transition-terrain, slope, altitude, groundwater profile, coastal regulation zones, etc. signify related risks of inaccessibility. The same influence can be established with other climatic conditions e.g., rainfall, snow, temperature, wind speed and pollution. The state of the built-up environment is also important in assessing risks posed to the population and can be measured in terms of population density, urbanisation levels, land use distribution, activity patterns, etc. Equally important as they influence the rate of transport development, are the alignment of transport lines, type of construction, and suitable technology for a given climate. Environmental information is highly used to validate the success of disaster-centric traffic management strategies.

The state of political development reflects in many ways the reliability of coordination among stakeholders, users' acceptance, and stringent enforcement of traffic bye-laws, ordinances and other laws, which are essential for traffic operations under unprecedented disaster conditions. The legal framework determines the applicability and difficulty of implementing special traffic ordinances and laws. Legal factors are determined by both local legislation and regional and national laws. International laws are sometimes needed to ensure multi-nations joint transport operations.

Several interrelationships could be easily evident among the STEEP vulnerability factors. As some relationships would naturally be negatively or otherwise correlated, the factors in each group must be considered in terms of mutually supportive or conflicting. Their correlation scale as 'strong', 'moderate', and 'insignificant' must be established.

Several methods have been developed for the estimation of weights of various factors to define vulnerability, which are mainly classified as subjective and objective methods. The difference between subjective and objective methods is that weights depend on the decision makers' knowledge and preferential judgment in the former case. Mathematical models have been used in the objective method to derive the weights (Ahmed et al., 2014). The present paper uses a catastrophe theory-based approach to avoid subjectivity (Ahmed et al., 2014).

2.3. Methodology

The system based on catastrophe theory is composed of factors, criteria, and indicators. In this study, STEEP factors and their descendent criteria are used. These factors encompass different capacities addressable by appropriate indices. The criteria of STEEP factors are carefully selected to ensure that they remain largely independent, fixed, and uncontrollable in the short-term. Major considerations while selecting criteria are adopting identical criteria from previously conducted transport vulnerability assessments and easy availability of data to monitor and validate the fulfilment of macro-environment thresholds. Furthermore, criteria are also formulated based on certain assumptions of practicality, reliability, and measurability of data. Once the criteria are formulated and fixed, the categorisation principles are applied to each individual criterion, thus, presenting clear differentiation in the sampled data. One of the considerations while selecting criteria is the easy availability of data; secondary sources are mainly used, i.e., data openly sourced through government offices, either online or printed materials. The open-source data of the government-released information are used to form criteria based on STEEP factors and indicators. The available indicators presented a representative description of the developmental states of society, technology, environment, economy, and politics used in the STEEP factors. To facilitate comparison and equate the units among differently formed criteria, the standardisation principles are formulated dependent on established rules, i.e., smaller is better (SIB) or larger is better (LIB). Depending on the number of criteria in a macro environment factor, normalisation formulae of the catastrophe are used to obtain index values. Finally, the weights are estimated for each criterion under each macro-environment factor. These weights are then used as a basis to present individual vulnerability states and thus, support decision making.

In catastrophe theory, two equations are generally used to standardise indices. Equation 1 is applied where larger values are considered to be better for certain data, e.g., literacy levels, income levels, use of traffic control devices, Gross Domestic Product, etc. On the other hand, equation 2 is used where smaller values are considered to be better, e.g., percentage of urban population, revenue earnings from traffic offences, the number of accidents, etc.

$$x_i' = \frac{x_i - x_{i(\min)}}{x_{i(\max)} - x_{i(\min)}} \quad (1)$$

$$x_i' = 1 - \frac{x_i - x_{i(\min)}}{x_{i(\max)} - x_{i(\min)}} \quad (2)$$

In the above equations, i is the index or attribute, x_i is the original value of i, x_i (max) and x_i (min) are maximum and minimum values in a given data. The raw data of the indicators were standardized to obtain multi-dimensional catastrophe fuzzy membership values between 0 and 1 (Wang et al., 2011). All the indicators given in Table 2 were standardised according to equations 1 and 2. Most of the indicators are a part of "Larger is Better" category. However, few indicators are observed to form the "Smaller is Better" category. Normalisation formula is the basis for calculations of the catastrophe model (Cheng et al., 1996). The formulae used for normalising the catastrophe model are given in Table 1.

This study is limited to developing factors, criteria, and indicators applicable to the Malaysian context. The vulnerability of each sub-sector of the transport sector is calculated by the multiplication of derived weight with the assigned rank and divided with the number of indicators present in the sub-sector.

The vulnerability analysis of the transport sector is carried out from the weights derived from the catastrophe model. The vulnerability of each sub-sector of transport, i.e., social, technological, environmental, economic, and political sectors, is determined separately in order to assess the vulnerability of each sub-sector with regards to the overall transport sector. The vulnerability values of each subsystem are calculated by the multiplication of derived weight with the assigned rank and divided by the number of indicators present in that sub-layer.

There are several different classification methods that can be used to organize data. The Equal Interval classification method is one such method where each class has an equal range of values; that is, the difference between the high and low values is equal for each class. This method is used if data is evenly distributed and it is required to emphasize the difference in values between the features. Following the principle of equal distribution, five indices of vulnerability in increasing order of vulnerability are formed in the present study. The index values were divided as; very low vulnerability <0.2, low vulnerability (0.3-0.4), medium vulnerability (0.5-0.6), high vulnerability (0.7-0.8), and very high vulnerability (0.9-1.0). The obtained values were further interpreted with the vulnerability index values by checking their qualification as 'very low', 'low', 'medium', 'high', and 'very high' indices.

Table 1. Normalization formulae.

Control variable	State variable	Model	Normalization formula
2	1	Cusp	$x_a = a^{1/2}$ *and* $x_b = b^{1/3}$
3	1	Swallowtail	$x_a = a^{1/2}, x_b = b^{1/3}$ *and* $x_c = c^{1/4}$
4	1	Butterfly	$x_a = a^{1/2}, x_b = b^{1/3}, x_c = c^{1/4}$ and $x_d = d^{1/5}$
5	1	Wigwam	$x_a = a^{1/2}, x_b = b^{1/3}, x_c = c^{1/4}, x_d = d^{1/5}$ and $x_e = e^{1/6}$

Source: Cheng et al., 1996.

All the relevant data from the State of Perlis is actualised and presented in percentages, where possible, elsewise the data were presented in actual magnitudes to mainly allow comparison between different pre-selected factors. Data were obtained from the three main sources, i.e., Socio-economic statistics of Perli (www.epu.gov.my), Transport Statistics of Malaysia (www.jpj.gov.my), and Environmental Time-series Malaysia (https://www.statistics.gov.my) were used to analyse 5 STEEP factors, 14 descendent criteria and 25 factors within. The other information on the political and administrative state was extracted from the official website of the government of Perlis.

3. DESCRIPTION OF STUDY AREA

The catastrophe theory is applied to the Malaysian State of Perlis due to a number of favourable factors. Firstly, this state presents a unique antecedent of a flood area representing the most vulnerable conditions of Malaysia; secondly, the size of the state is appropriate to be examined for macro-level assessment, and finally, the easy accessibility of data greatly facilitates to undertake this case study. The State of Perlis is surrounded by Thailand in the north, and Kedah in the south, whilst its western coastline is bordered by the Straits of Malacca (Lawal et al., 2014). It is the smallest State if the Federal Territory is not included. The State has an area of 795 km² and a total population of 240,200 inhabitants (Department of Statistics Malaysia, Official Portal, https://www.dosm.gov.my/v1/#).

The region experiences an equatorial maritime climate. Rainfall occurs mainly from April to November, with peak periods in April–May and August-October. The period from December to March is often virtually dry. Average rainfall ranges from about 1750 mm in north Perlis to 3250 mm in the extreme south of Kedah (Fig. 1).

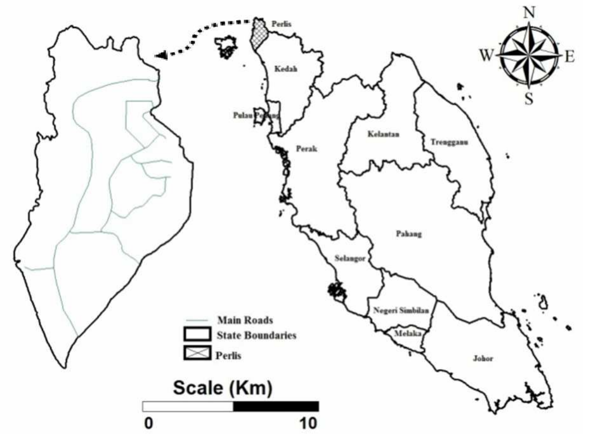

Fig. 1. Perlis State on the map of Peninsular Malaysia.

Variations in daily temperatures are very small. The average daily temperature is 27ºC, with the maximum at 32°C and the minimum at 21°C throughout the year. The relative humidity is high, with mean monthly values of 78% in the dry period and 85% in the peak rainy season. Annual mean open water evaporation ranges from 1700 to 2000 mm, with high and low mean daily rates of 6 mm and 3.7 mm (Arafin and Lee, 1985). Frequent floods are becoming common, inundating large parts of the Perils. The government of Perlis has a greater concern about regular floods as it affects the well-being of the residents. In December 2005, a nonstop rain over three-days flooded two-thirds of Perlis, which caused the relocation of more than 16,000 people, destroyed an estimated 25,000 ha of paddy fields, and losses were likely to be over RM 81 million (16.23 million EUR). Perlis and neighbouring Kedah were affected by a series of floods in November 2010 that compelled many people to evacuate their houses. During the April 2011 flood, the number of flood 4,761 persons were evacuated at relief centres all over Perlis state (Lawal et al., 2014; Hafiz and Rahim, 2012). Annual flooding events mainly caused by seasonal monsoon is frequently affecting all State of Malaysia, which accounts for significant losses (Safiah Yusmah et al., 2020). A recent flooding event in December, 2022 in Perlis, Perak, and Selangor States compelled 157 families / 567 persons to be displaced in nine evacuation centres (ADINet, 2022).

4. RESULTS AND DISCUSSION

The vulnerability of the transport sector was analysed on a scale of 0 to 1 based on the weights of macro-environmental factors estimated using catastrophe theory. The macro-environmental factors considered in this study, the criteria of each factors, and different features or classes of each criterion are shown in the first, second, and third columns of Table 2. The number of criteria under different factors of STEEP is different. For example, three criteria were considered for the social factor: physical disabilities, educational disabilities, and personal disabilities. The vulnerability of each social criterion can be assessed using different indicators. For example, physical disabilities can be estimated by the percentage of physically disable people in the total population. Some criteria indicate a broader perspective and, therefore, need more indicators to assess them comprehensively. For example, personal disabilities is a much broader term and therefore needs to be assessed using more indicators. In this study, four indicators are proposed for assessing personal disabilities: percentage of the population of different age groups, percentage of population by gender, percentage of population speaks different languages, and percentage of the population of different income groups.

The value of each class of indicators is obtained from the sources mentioned in Section 3. and provided in the fifth column of Table 2. The raw data is normalized using either equation (1) or (2). The normalization method is mentioned in the sixth column of Table 2. LIB means equation (1) is used where larger values indicate more vulnerability. On the other hand, SIB means equation (2) was used where smaller values represent more vulnerability. Standardized values are given in the seventh column of Table 2. Catastrophe models are used on standardized values to estimate the weight of each vulnerability indicator.

A control variable is based on the number of categories formed, i.e., criteria of 'personal disabilities (B3)' under the indicator '% population by age (C3), three categories are formed, hence in the case of three control variables, swallowtail type of model is applied. The control variables in the catastrophic model can be computed from the initial fuzzy subordinate function based on normalization formulas (Ahmed et al., 2014) shown in the above table. During calculation, two principles are applied, i.e., non-comparative and comparative. In a non-comparative principle, the function of the control variables cannot be replaced with each other within the system. Therefore, the smallest value of control variables (a, b, c, d) can be used for the system (Yomo et al., 2019), while in comparative principles, the control variables can fill up the deficiency of each other. So, their mean value can be used for the system. For example, the indicator '% distribution of metalled roads by type (C7)' under vulnerability assessment criteria 'state of transport infrastructure development (B4)' in the group of vulnerability assessment factor 'Technological factors (A2)' has three categories, namely, Paved (X15), Gravel (X16) and Earth (X17). Therefore, the catastrophe model 'Swallowtail' is required to be applied in this case. The vulnerability of different types of mettaled roads (used in the rainy season) can be categorized as follows: Paved road is most vulnerable, following Gravel road and Earth road. Therefore, the maximum vulnerability factor 'x_{max}' is estimated for Paved road as 0.780 and 'x_{min}' is estimated for Earth road as '0.100'. After standardization of raw data, the normalized values are obtained from normalization formulas of the Catastrophe theory (Ahmed et al., 2014) given in Table 2. Therefore, the weight of indicator '% distribution of metalled roads by type (C7)' is calculated using the Swallowtail model (Shahinuzzaman et al., 2021) as, X15=((1)^0.5)=1, X16=((0.12)^0.33)=0.31 and X17=((0.1)^0.25)=0.001. The average of the indicators, C7= (X15+ X16+ X17)/3=0.44.

Table 2. Details of system of assessment based on Catastrophe Theory - A case of floods in the Perlis State of Malaysia.

Factor	Criteria	Indicator	Category	Data	Standard.		Model	Index	Weight
Social factors (A1)	Physical disabilities (B1)	% of population by disabilities (C1)	Normal (X1)	99.71	LIB	0.00	Cusp	0.00	0.50
			Disable (X2)	0.029	LIB	1.00		1.00	
	Educational disabilities (B2)	% of population by literacy (C2)	No literacy (X3)	10.0	LIB	0.00	Cusp	0.00	0.50
			Literacy (X4)	90.0	LIB	1.00		1.00	
	Personal disabilities (B3)	% of population by age (C3)	<14 (X5)	25.4	SIB	0.70	Swallowtail	0.84	0.61
			15-64 (X6)	66.8	SIB	0.00		0.00	
			>65 (X7)	7.80	SIB	1.00		1.00	
		% of population by gender (C4)	Male (X8)	50.0	LIB	0.50	Cusp	0.71	0.75
			Female (X9)	50.0	LIB	0.50		0.80	
		% of population by language (C5)	Malaysian (X10)	97.5	LIB	1.00	Cusp	1.00	0.50
			Non-Malaysian (X11)	2.5	LIB	0.00		0.00	
		% of population by income (C6)	Low (<RM 2999) (X12)	61.0	SIB	0.00	Swallowtail	0.00	0.57
			Medium(RM3000-6999) (X13)	28.0	SIB	0.34		0.70	
			High (>RM 7000) (X14)	11.0	SIB	1.00		1.00	
Technological factors (A2)	Transport infrastructure (B4)	% distribution of metalled roads by type (C7)	Paved (X15)	78.0	LIB	1.00	Swallowtail	1.00	0.44
			Gravel (X16)	12.0	LIB	0.03		0.31	
			Earth (X17)	10.0	LIB	0.00		0.00	
		Number of cars per 1000 inhabitants (C8)	(X18)	90.0	LIB	1.00	Cusp	1.00	0.50
			(X19)	80.0	LIB	0.00		0.00	
	Traffic control (B5)	% traffic control (C9)	With (X20)	78.0	LIB	1.00	Cusp	1.00	0.50
			Without (X21)	22.0	LIB	0.00		0.00	
	Vehicle	% vehicle by age	<12 (X22)	58.0	LIB	1.00		1.00	0.50

	technology (B6)	(C10)	12+ (X23)	42.0	LIB	0.00	Cusp	0.00	
Environmental factors (A3)	Physiography (B7)	% of inaccessible area (C11)	Accessible area (X24)	85.8	SIB	0.00	Cusp	0.00	0.50
			Inaccessible area (X25)	14.2	SIB	1.00		1.00	
	Climate (B8)	Rainfall (mm/yr.) (C12)	High (X26)	2000	SIB	0.00	Cusp	0.00	0.50
			Low (X27)	1800	SIB	1.00		1.00	
		Average temperature C (C13)	Minimum (X28)	23.9	SIB	1.00	Cusp	1.00	0.50
			Maximum (X29)	32.7	SIB	0.00		0.00	
		Population density (C14)	High (X30)	301.0	SIB	0.00	Cusp	0.00	0.50
			Low (X31)	205.0	SIB	1.00		1.00	
	Built environment (B9)	% of land use distribution (C15)	Built-up (X32)	24.1	LIB	0.20	Butterfly	0.73	0.59
			Agriculture (X33)	5.87	LIB	0.00		0.00	
			Water bodies and wetland (X34)	0.29	LIB	1.00		1.00	
			Forest (X35)	69.3	LIB	0.38		0.62	
		% of urban population (C16)	Urban (X36)	51.4	LIB	1.00	Cusp	1.00	0.50
			Suburban (X37)	48.6	LIB	0.00		0.00	
Economic factors (A4)	Economic state of population (B10)	Vehicles per person (C17)	Good (X38)	1.00	LIB	0.00	Cusp	0.00	0.50
			Better (X39)	2.00	LIB	1.00		1.00	
		% of population groups (C18)	LIG (X40)	60.9	LIB	0.00	Swallowtail	0.00	0.56
			MIG (X41)	27.7	LIB	0.33		0.69	
			HIG (X42)	11.4	LIB	1.00		1.00	
	Economic state of state (B11)	GDP per total population of state (C19)	High (X43)	10802	LIB	1.00	Cusp	1.00	0.50
			Low (X44)	5401	LIB	0.00		0.00	
	Economic state of nation (B12)	Gross domestic product (C20)	High (X45)	0.045	LIB	1.00	Swallowtail	1.00	0.62
			Medium (X46)	0.040	LIB	0.67		0.87	
			Low (X47)	0.030	LIB	0.00		0.00	
Political factors (A5)	Political and administrative attitudes (B13)	Political attitude (C21)	(X48)	1.00	LIB	0.00	Swallowtail	0.00	0.59
			(X49)	5.00	LIB	0.44		0.77	
			(X50)	10.00	LIB	1.00		1.00	
		NGO and Welfare Trust (C22)	(X51)	25	LIB	0.00	Swallowtail	0.00	0.60
			(X52)	30	LIB	0.50		0.80	
			(X53)	35	LIB	1.00		1.00	
		Total time spent in the office (C23)	(X54)	59.0	LIB	1.00	Cusp	1.00	0.50
			(X55)	55.0	LIB	0.00		0.00	
	Political stability (B14)	Revenue earning from traffic offences (C24)	High (X56)	998075	SIB	0.00	Cusp	0.00	0.50
			Low (X57)	499037	SIB	1.00		1.00	
		Traffic accidents (C25)	Death (X58)	90	SIB	1.00	Swallowtail	1.00	0.60
			Major Injuries (X59)	225	SIB	0.50		0.80	
			Minor injuries (X60)	360	SIB	0.00		0.00	

The weights of different transport vulnerability indicators estimated using catastrophe theory are given in the last column of Table 2. The influence of different indicators on transport vulnerability was identified from the weight of the indicator. A higher weight indicates higher influence of the indicator on vulnerability. The study identified that the educational disabilities of the population due to age (0.61), personal disabilities due to gender (0.75), and personal income (0.57) were the major contributors to transport vulnerability when socio-demographic factors were considered. Among the other socio-demographic factors, language barrier (0.50), the literacy level of the population (0.50), and physical disabilities of the population contributed moderately to transport vulnerability.

Higher weight in socio-demographic trends in the flood-prone State of Perlis suggests the general preference and requirements for transport services in disasters. Similarly, the vulnerability of the transport users of different social groups can be based on social factors, i.e., elderly, disabled, and people with special needs in transport services. The general illness and disabilities in the population demand special transport services. Likewise, some transport user groups as children, elderly and non-native populations would highlight the need for special tools of information. The knowledge of the vulnerable transport users' such as population by vulnerable age, gender, etc., is indicative of special mobility needs in transport services. The study urges transport planners and policymakers to pay attention to making the transport system more usable for the elderly, disabled, and people with special needs to improve their effective mobility. Also, decision-makers need to focus on the accessibility of low-income populations to make the transport system more affordable and public transport for all.

Transport interactions about the state of society, technology, environment, economics, and politics are fixed and cannot be changed in the short-term, such as transport interactions with society, land-use, etc. Micro, Meso, and Macro environments must be considered as an aggregate of forces influencing sustainable urban development and combining both the factors that have a direct impact and those whose impact is indirect (Sloan et al., 1999). Forest land contributes the majority of the land uses (69.3%), and around 24% of land is under built-up area. Perlis is still a 'green' State in Malaysia (Koridor Utara Malaysia, 2013). Catastrophic analysis result suggests that land use distribution (0.59) is found to have the most influence among the environmental factors, followed by total urban population (0.5) and population density (0.5). Among the economic factors considered in the present study, low to medium income conditions of people (0.56) as well as the gross domestic product (0.62) further added to transport vulnerability. Unfavourable political attitude (0.59) toward transport sector development in view of disasters, poor support of the non-governmental organisation, welfare trust, etc. (0.60), as well as poor administrative measures to mitigate traffic accidents and incidents (0.60) contributed significantly to vulnerability.

Comparing all the factors belonging to different sub-systems together, it is observed that social factors have comparative more influence on transport vulnerability, followed by economic, political, environmental, and technical factors. Among the social factors, gender, age, and income play a major role in defining vulnerability. Among the other factors, economic condition of the state, land use distribution, political attitude, role of civic society (NGO) were also found to have significant influence. Therefore, it can be remarked that the immobility of the mass population and the unavailability of sufficient infrastructure and technology are the major factors of high vulnerability. Gender equality in the transport sector should be promoted in the planning, designing, and operations of transport infrastructure and services.

The rate of urbanization in Perlis is expected to grow from 51.4% in 2010 to 63% in 2020, and the same is further expected to grow further by 75% by 2030, as per the estimate of Perlis Strategic Development Plan 2012-2030 (Koridor Utara Malaysia, 2013). Flood management in Perils state has yet to harmonize with the rapid urbanization. A large percentage of the population is in the low-income category (61%), followed by 28% medium-income, and only 11% population is in high-income category (Table 2). Accessibility to the low-income population to the transport system should be greatly improved to make the transport system more affordable.

Social aspects must give prime thrust to reduce overall vulnerability in the transport sector as the socio-economic and demographic profile majorly influences the transport phenomenon in the State of Perlis. Several interrelationships (strong, moderate, and insignificant) can be evident among the STEEP factors from the present analysis.

5. CONCLUSIONS

The National Government of Malaysia has aligned the SDG targets with the 11th Malaysia Plan (11MP) and prepared an initial assessment report in 2018 (Department of Statistics, Malaysia 2018). Further, in 2019, the Malaysian National Government launched the ambitious National Transport Policy (2019-2030) aiming to achieve double public transport usage (from 20% to 40%) by 2030 (Ministry of Transport, Malaysia 2019). The frequent floods in most of the States in Malaysia call for a new methodological intervention to quantify various factors and indicators that influence transport vulnerability. It is expected that the new evaluation method will help the policymakers to identify the overall vulnerability of the transport sector and areas that require improvement, which will help to enhance public transport usage in Malaysia.

The Perlis State of Malaysia is the smallest State in Malaysia, located northern part of the west coast of peninsular Malaysia. Frequent floods are common in the Perlis State. The present study explored the relationships of transport vulnerability with macro-environmental factors that can help in understanding the localised issues for policymakers. Various factors responsible for the vulnerability of transport during disasters have been assessed and analysed using catastrophe theory to avoid subjectivity involved in assessing vulnerabilities. The study reveals that social factors contribute more to transport vulnerability compared to other factors. Among the social factors, gender, age, and income were found to play a significant role in defining vulnerability. It can be concluded that the immobility of the mass population and the unavailability of sufficient infrastructure and technology are the major factors of high vulnerability.

Forest and agriculture accounted for the majority of the land use in Perlis (Koridor Utara Malaysia, 2013). The state of the built-up environment, including land use distribution, is an important factor in assessing risks posed to the population. Both land use and transport equally focus on microscopic and macroscopic vulnerability assessment. The characteristics of the built-up and natural environments, including water bodies and wetlands, provide necessary inputs to estimate transport vulnerabilities. Policymakers need to plan resilient built environments that require understanding localised transport vulnerability issues and areas such as social, technological, environmental, economic, and political that require improvement.

The proposed catastrophe theory-based evaluation method in one had grossly reduced subjectivity, and also it calculates the importance of one criterion over others by its inner mechanism (Ahmed et al., 2014). Therefore, it can be remarked that the influence of different factors estimated in this study reflects real field conditions and can be used to reduce transport vulnerability more effectively. The present study acts as an input for policymakers to understand and address accessibility, gender equality, and state apathy towards transport sector development in view of disasters. The application of catastrophe theory enables organisations to optimise resource allocation for complex situations with an uncertain future. It is expected that the study can help to develop knowledge for pre-disaster management by undertaking a complex analysis of macro-environment factors and criteria. However, it is suggested that the priority areas would require improvement.

The assessment from this work can be further expanded to include pre-determined and undetermined factors for the refinement of vulnerability. Due to the limitation of data, only a few factors have been considered for the assessment of transport vulnerability to disaster. More factors related to socio-economic conditions, physio-environmental status, and technical ability should be considered. The study can be validated in the future with primary data collected during flood events. The study can be repeated in other regions of Malaysia to assess the influence of various factors more accurately. Other data-driven approaches can be used to compare the results obtained in the present study using catastrophe theory. The influence of different factors determined by catastrophe theory partially depends on the classification method used. In the future, other classification methods can be used and compared with the results obtained in the present study to determine vulnerability factors more clearly.

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