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Cross-impact analysis of factors affecting urban mobility in Chiang Mai, Thailand

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Abstract

This paper aims to explore urban mobility and analyze the related empirical probability factors in Chiang Mai. Cross-impact analysis (CIA) techniques and Ethnographic Delphi Futures Research technique (EDFR) were used as tools. The data was collected by interviews with 10 experts, people who have experience in urban planning and urban mobility development from government and the private sectors. The results showed 13 factors affecting urban mobility in Chiang Mai. Analysis revealed that the main factors affecting urban mobility are accessibility, comfortable travel, and travel safety. Next, the main factors were analyzed to find probable futures for urban mobility. Then, Monte-Carlo simulation technique was used to create and randomize 26 scenarios related to factors affecting urban mobility. In conclusion, this study found that this model was able to define the factors that affect the possibility of developing urban mobility in Chiang Mai. All affected factors were related through the development in urban mobility and can be used as variables in decision-making for urban planning, infrastructure development, and investment in the future. Therefore, the model can be used as a tool for urban planners and developers for urban decision preparation in the future.

Keywords: *Chiang Mai; cross impact-analysis; Ethnographic Delphi Futures Research; factors influencing; urban mobility; urban planning.*

1. Introduction

Urban mobility is the ability to move passengers and goods to different locations. This increases the competitiveness in a city and is defined by the city's infrastructure, population distribution, and socio-economic needs (Bassolas et al., 2019). Dependence on private cars will also increase. Therefore, urban traffic will affect most of the population because it will create expenses required to solve many problems, such as reducing congestion on the road. Reducing air pollution and reducing noise pollution improve deteriorating landscapes and public spaces, increasing security and quality of life for urban residents (Maltese, Gatta, & Marcucci, 2021).

The urban mobility index was developed over many years (Regmi, 2020). The major indexes published in the past thirteen years have been developed from different methods, each index with its advantages according to the characteristics of the indicators in each region. It was found that the factors influencing urban mobility (Arslan, Durak, Gebesce, & Balcik, 2018; Fontoura, Chaves, & Ribeiro, 2019; Bassolas et al., 2019; Punzo, Panarello, & Castellano, 2021) include social factors, economic factors, environmental factors, accessibility, travel safety, and convenience, each of which has secondary factors that influences the main factor, e.g. factors that influence accessibility, such as travel time and affordability (Dewita, Burke, & Yen, 2020), factors that influence travel safety, such as road conditions and weather, factors that influence comfort, such as vehicle volume, accessibility, trip frequency, modal split, the ratio of public transport supply, and delay performance and demand (Suryani, Hendrawan, Adipraja, Wibisono, & Dewi, 2021) etc. Interviews with experts and stakeholders in urban mobility helped to identify factors that further influence urban mobility.

From a review of the methods used to analyze impact on urban mobility, it was found that many models, techniques, and methods have been applied in scientific research for urban mobility planning and continuous urban development, such as system dynamics (SD) simulation and scenarios (Suryani et al., 2021), the probit choice models, the structural equation model (Tyrinopoulos, & Antoniou, 2013), the DCCA cross-correlation coefficient (ρDCCA) method (Azevedo, Sampaio, Moret, & Murari, 2021), the statistical method applied to determine correlation by analyzing co-movements between the time series, the technique of multi-criteria analysis AHP (Analytic Hierarchy Process) (Fraile, Sicilia, González, & González, 2016), a fuzzy-analytic hierarchy process (AHP) model, Delphi method (Anastasiadou, Gavanas, Pyrgidis, & Pitsiava-Latinopoulou, 2021), and the SIMUS (Sequential Interactive Modelling for Urban Systems) method were applied for arraying variants of options and choice of best type of a vehicle system. This last approach gives possible future actions in form of linear programming (Stoilova, 2019). This research has selected cross impact analysis as a step to assess the situation obtained from Delphi techniques by creating an event matrix and the result of the trend. By creating both horizontal and vertical the performance analyzes what marks the matrix as to how feasible it is and shows the relationship between events the Cross-impact matrix analysis of the future image using the same median criteria as Delphi techniques and using percentile values to analyze the correlation of variables.

It is interesting to find out what factors affect urban mobility in major cities of each part of the country in order to outline urban mobility development in a sustainable way. In this case, Chiang Mai province was chosen as the area of the study since it is the second largest city after Bangkok. The province is considered a center city in Northern Thailand for education, trade, service, and transportation, as well as arts and culture. These elements have attracted immigrants to Chiang Mai for work, starting a business, education, and other purposes. Focusing on Chiang Mai province, for urban mobility to be more streamlined, public transport access must be improved, commuting time decreased, and commuting made more comfortable and safer. To prove this, data was gathered through interviews with experts and stakeholders of urban mobility; then, the relationship between factors was analyzed to create an influence diagram of the factors influencing urban mobility. Main factors from the analysis and influence diagrams were then analyzed into events using cross effect analysis to determine the probabilities of each factor (Panula-Ontto et al., 2018). The effect of using a cross-effect model is to create a situation by determining the probabilistic factor. The relationship between the events in the cross-effect analysis in the normalization process was modeled following the Monte Carlo process. Each run of the model creates a visualization of future events or simulations including the occurrence of certain events (Panula-Ontto, 2019). Consequently, the result of this study reveal decision making determinants to frame the flagship projects of sustainable urban infrastructure development for a large city.

2. Objectives

The goal of this research was to guide the urban mobility development of Chiang Mai in the future by finding factors affecting urban mobility, to analyze interrelationship and probability of factors that are influencing the development of urban mobility using EDFR and CIA techniques, and to find the most probable event for a change in urban mobility from forecasts (simulation).

3. Materials and methods

3.1 Study area: Chiang Mai comprehensive plan

The boundary of the study area is within 430 sq. km of the Chiang Mai comprehensive plan. This covers the area of Muang Chiang Mai District and surrounding areas in Mae Rim District, San Sai District, San Kamphaeng District, Saraphi District, Hang Dong District, and Doi Saket District.

The urban boundary has extended beyond the administrative boundary of Chiang Mai, reaching the neighboring districts. The development of the urban boundary has brought much prosperity to the urban area, while also bringing about several negative effects, including social, environmental, and transport problems.

3.2 Data collection

The research method involved identifying factors influencing urban mobility, collecting factors of influence for urban mobility from literature and expert interviews. The examined factors were scored by a five-point rating system and the collected data were analyzed by statistical techniques. The factors for urban mobility were determined by interrelation, interaction, occurrence probability, and conditional probability through the use of the CIA method (Chiracharoenwong, Dumrongchai, Thiengburanathum, & Asasuppakit, 2020). Monte Carlo simulation was conducted for future event analysis.

Reviewing the documents and literature that deals with urban mobility, it was found that the indicators of urban mobility have been studied in many works using different metrics. Factors that affect this research were identified, and a total of 24 factors that affect urban mobility were collected from the literature review. A checklist of these influencing factors was created, as shown in Table 1. All 24 factors influencing urban mobility were evaluated using a pattern assessment, such as a five-point Likert scale (1, not at all influential, 2 slightly influential, 3 somewhat influential, 4 very influential, 5 extremely influential). They were then passed to an expert panel to screen and select the main factors influencing urban mobility in Chiang Mai,. The criteria used are a median greater than 3.5, a difference between median and mode not more than 1, and an interquartile range not more than 1.5.

The expert panel comprised 10 experts. It consisted of 4 executives or government representatives (2 from Chiang Mai Provincial Transport Office, 2 from Chiang Mai Municipality), 3 representatives from the private sector (1 from Nakorn Lanna Transport Cooperative Limited and 2 from Regional Transit Corporation (RTC)), and 3 academicians. All of them have more than 10 years of experience in public transport development and urban development.

Table 1 Factors affecting urban mobility

	Indicators	Literature
1	Affordability	Lam and Head, 2011, Perra, Sdoukopoulos, & Pitsiava-Latinopoulou, 2017, Gillis, Semanjski and Lauwers, 2016, Tafidis, Sdoukopoulos and Pitsiava-Latinopoulou, 2017, Jain and Tiwari, 2017, WBCSD, 2015
2	Inclusive Access	Lam and Head, 2011, Perra et al. 2017, Gillis et al. 2016, Jain and Tiwari, 2017, WBCSD, 2015
3	Vehicle pollution	Lam and Head, 2011, Tafidis et al., 2017, (Jain and Tiwari, 2017, WBCSD, 2015
4	Traffic Safety	Lam and Head, 2011, Perra et al., 2017, Gillis et al., 2016, Tafidis et al., 2017, Gerlach, Richter and Becker, 2016, Jain and Tiwari, 2017
5	Access to mobility services	Lam and Head, 2011, Perra et al., 2017, Costa, Neto and Bertolde, 2017, Gillis et al., 2016, Tafidis et al., 2017, Nicolas, Pochet and Poimboeuf, 2003, Jain and Tiwari, 2017, Macedo, Rodrigues and Tavares, 2017, Mitsakis et al., 2013, WBCSD, 2015
6	Quality of public area	Lam and Head, 2011, Moeinaddini, Asadi-Shekari and Shah, 2015, Perra et al., 2017, Gillis et al., 2016, Tafidis et al., 2017, Nenseth, Christiansen and Hald, 2012, Jain and Tiwari, 2017, Macedo et al., 2017, WBCSD, 2015
7	Functional diversity	Lam and Head, 2011, Perra et al., 2017, Costa et al., 2017, Gillis et al., 2016, Tafidis et al., 2017, Nicolas et al., 2003, (Jain and Tiwari, 2017, Macedo et al., 2017, Mitsakis et al., 2013, WBCSD, 2015
8	Travel time	Lam and Head, 2011, Moeinaddini et al., 2015, Perra et al., 2017, Gillis et al., 2016, Tafidis et al., 2017, Nenseth et al., 2012, Nicolas et al., 2003, Jain and Tiwari, 2017, Mitsakis et al., 2013, WBCSD, 2015

	Indicators	Literature
9	Economic opportunity	Lam and Head, 2011, Tafidis et al., 2017, Nenseth et al., 2012, Jain and Tiwari, 2017, Macedo et al., 2017, WBCSD, 2015
10	Net public finance	Lam and Head, 2011, Gillis et al., 2016, Tafidis et al., 2017, WBCSD, 2015
11	Mobility space usage	Lam and Head, 2011, Moeinaddini et al., 2015, Perra et al., 2017, Gillis et al., 2016, Tafidis et al., 2017, Nenseth et al., 2012, WBCSD, 2015
12	Green House Gases (GHG)	Lam and Head, 2011, Gillis et al., 2016, Tafidis et al., 2017, Gerlach et al., 2016, Nicolas et al., 2003, Nenseth et al., 2012, Jain and Tiwari, 2017, Mitsakis et al., 2013, WBCSD, 2015
13	Congestion and delay	Lam and Head, 2011, Perra et al., 2017, Gillis et al., 2016, Tafidis et al., 2017, Jain, & Tiwari, 2017, WBCSD, 2015
14	Energy Efficiency	Lam and Head, 2011, Perra et al., 2017, Gillis et al., 2016, Tafidis et al., 2017, Gerlach et al., 2016, Nicolas et al., 2003, Jain and Tiwari, 2017, Macedo et al., 2017, WBCSD, 2015
15	Opportunity for active mobility	Lam and Head, 2011, Gillis et al., 2016, Jain and Tiwari, 2017, WBCSD, 2015
16	Intermodal connectivity	Lam and Head, 2011, Perra et al., 2017, Costa et al., 2017, Gillis et al., 2016, Mitsakis et al., 2013
17	Intermodal integration	Lam and Head, 2011, Costa et al., 2017, Gillis et al., 2016, Mitsakis et al., 2013, WBCSD, 2015
18	Occupancy rate	Lam and Head, 2011, Perra et al., 2017, Gillis et al., 2016, Jain and Tiwari, 2017, Mitsakis et al., 2013
19	Comfort and pleasure	Lam and Head, 2011, Moeinaddini et al., 2015, Perra et al., 2017, Gillis et al., 2016, Macedo et al., 2017, WBCSD, 2015
20	Security	Lam and Head, 2011, Perra et al., 2017, Gillis et al., 2016, Tafidis et al., 2017, (Jain and Tiwari, 2017, Macedo et al., 2017, WBCSD, 2015
21	Modal split	Perra et al., 2017, Gerlach et al., 2016, Nicolas et al., 2003, Jain and Tiwari, 2017, Mitsakis et al., 2013
22	Parking spaces	Moeinaddini et al., 2015, Nenseth et al., 2012, Macedo et al., 2017, WBCSD, 2015
23	Fatalities	Mitsakis et al., 2013, WBCSD, 2015
24	Noise hindrance	Gillis et al., 2016, Jain and Tiwari, 2017, Mitsakis et al., 2013, WBCSD, 2015

3.3 Data analysis

This is an Analysis and screening to find the joint opinions of experts using Delphi techniques. First, content analysis was performed with data collected from a literature review and verified by 10 experts to collect factors that affect urban mobility from Table 1. Based on the EDFR approach, experts defined the interrelation of examined factors into three events as optimistic, pessimistic and most likely (Gordon, 2021). Second, experts gave a primary probability value (probability of occurrence) of each event. The relationship between the factors influencing the urban mobility shows as a map of cause-effect relation in Figure 1, and the primary probabilities of the events of all examined factors shows in Table 2.

For the research method, cross-effect technique was used to analyze the inter-factor effect on the probabilities of posterior factors. The operation steps are as follows:

1. The EDFR technique is used to search for factors related to and affecting urban mobility of Chiang Mai. Experts help determine the relationship between events, which is divided into 3 levels of interaction: Significant SIG+ = +3, SIG- = -3; Moderate MOD+ = +2, MOD- = -2; and Slight SLI+ = +1, SLI- = -1. These factors are also analyzed by cross-effect analysis technique in order to find the correlation and effect between the volatility factors, along with the volatility of these factors. As a result, the development of urban mobility is uncertain to assess the influence between variables or between events. The amount of vehicles, for example, is inversely proportional to the speed of travel, i.e. when the volume of vehicles increases, the traveling speed decreases (SIG-). Travel time also varies

directly with the distance, meaning if the travel distance is short, the travel time will be short (SIG+). These relationships are shown in Figure 1.

2. Probability estimates are found for all events using the initial symbol. Probability (P(i)) is obtained by collective judgment of experts. These are shown in Table 2.

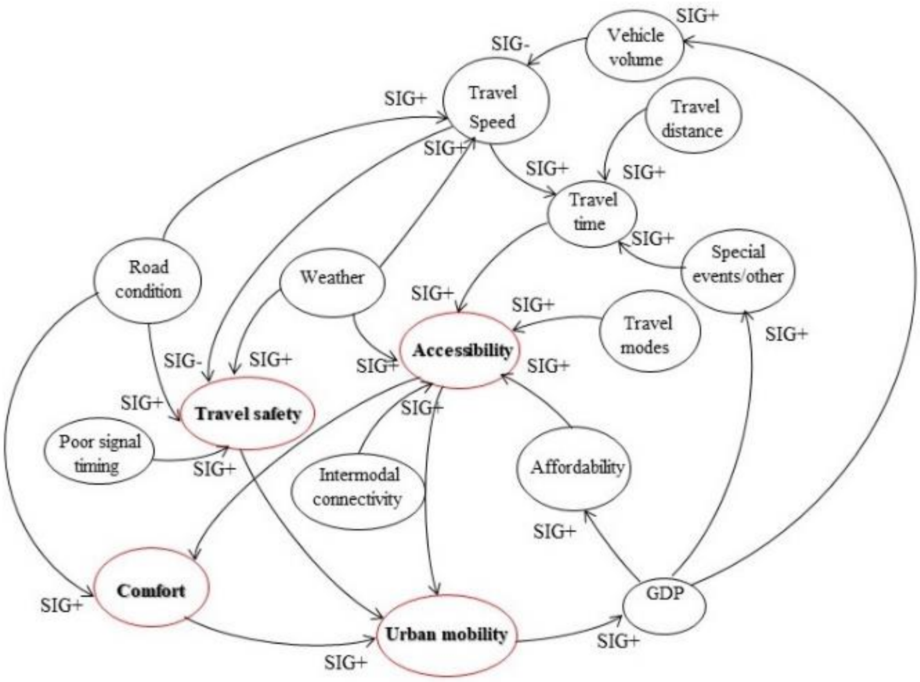

Figure 1 Cause-effect relation map of factors affecting urban mobility from expert samples

Table 2 The initial probability of each event of factors influencing urban mobility

Factors	Event	Initial Probability
GDP (A)	good (A1)	0.2
	moderate (A2)	0.4
	poor (A3)	0.4
Vehicle volume (B)	low (B1)	0.1
	average (B2)	0.3
	high (B3)	0.6
Travel distance (C)	short (C1)	0.1
	median (C2)	0.5
	far (C3)	0.4
Road condition (D)	good (D1)	0.6
	moderate (D2)	0.3
	bad (D3)	0.1
Weather (E)	good (E1)	0.3
	moderate (E2)	0.4
	bad (E3)	0.3
Travel speed (F)	fast (F1)	0.3
	moderate (F2)	0.5
	slow (F3)	0.2
Special events (G)	small (G1)	0.2
	median (G2)	0.4

Factors	Event	Initial Probability
	big (G3)	0.4
Travel time (H)	short (H1)	0.2
	median (H2)	0.3
	long (H3)	0.5
Affordability (I)	inexpensive (I1)	0.3
	Acceptable (I2)	0.3
	expensive (I3)	0.4
Accessibility (J)	good (J1)	0.6
	moderate (J2)	0.3
	poor (J3)	0.1
Travel safety (K)	Very safe (K1)	0.4
	safe (K2)	0.4
	Unsafe (K3)	0.2
Comfort (L)	good (L1)	0.4
	moderate (L2)	0.4
	poor (L3)	0.2
Urban Mobility (M)	good (M1)	0.6
	moderate (M2)	0.3
	poor (M3)	0.1

3. With the results from the first round of expert answers, the table of cross-effect relationship of all events of the examined factors revealed. Experts specified the cross-impact index of the interaction events in the table of cross-impact relationship (Alarcón & Ashley, 1998; Han & Diekmann, 2001a; Honton, Stacey, & Millett, 1985) as shown in Table 3. The EDFR second round shows the example of response from experts in Table 4.

Table 3 Cross-impact relation patterns

Index value	Meaning	Abbreviation
3	significantly in the same direction	SIG+
2	moderately in the same direction	MOD+
1	slightly in the same direction	SLI+
-1	slightly in the opposite direction	SLI-
-2	moderately in the opposite direction	MOD-
-3	significantly in the opposite direction	SIG-

Table 4 Data analysis of the influencing factors urban mobility by experts

Indicators	Experts										Mode	Median	Mean	Med-Avg	Q3-Q1
	1	2	3	4	5	6	7	8	9	10					
Congestion and delay	2	3	5	4	4	3	5	5	2	2	2	3.5	3.50	0.00	3
Travel time	5	4	5	3	5	3	3	3	4	2	3	3.5	3.70	-0.20	2
Comfort and pleasure	5	3	3	3	5	4	4	3	5	5	5	4.0	4.00	0.00	2
Parking spaces	4	4	2	5	5	4	1	1	4	1	4	4.0	3.10	0.90	3
Opportunity for active mobility	5	2	2	1	3	2	3	1	1	5	2	2.0	2.50	-0.50	2
Intermodal connectivity	3	4	4	2	3	5	5	4	5	3	3	4.0	3.80	0.20	2
Intermodal integration	2	3	5	1	5	2	5	4	5	2	5	3.5	3.40	0.10	3

Indicators	Experts										Mode	Median	Mean	Med-Avg	Q3-Q1
	1	2	3	4	5	6	7	8	9	10					
Modal split	4	1	4	5	5	2	4	4	4	1	4	4.0	3.40	0.60	2
Mobility space usage	5	5	4	1	2	3	3	3	4	5	5	3.5	3.50	0.00	2
Inclusive Access	4	4	4	4	2	4	4	5	1	2	4	4.0	3.40	0.60	2
Access to mobility services	3	4	2	4	3	3	4	4	5	3	3	3.5	3.50	0.00	1
Affordability	4	3	5	5	4	5	4	3	2	3	4	4.0	3.80	0.20	2
Economic opportunity	4	4	2	4	4	1	3	2	3	4	4	3.5	3.10	0.40	2
Net public finance	2	2	4	5	3	4	1	5	1	3	2	3.0	3.00	0.00	2
Occupancy rate	4	3	5	4	4	1	3	1	2	4	4	3.5	3.10	0.40	2
Quality of public area	1	4	4	1	3	1	4	2	3	1	1	2.5	2.40	0.10	3
Functional diversity	1	3	5	4	4	4	3	3	2	2	3	3.0	3.10	-0.10	2
Green House Gases (GHG)	3	5	4	3	4	4	4	4	2	5	4	4.0	3.80	0.20	1
Vehicle pollution	4	2	3	3	3	1	3	3	1	5	3	3.0	2.80	0.20	1
Energy Efficiency	4	5	2	3	5	3	2	2	5	3	5	3.0	3.40	-0.40	3
Noise hindrance	5	3	3	1	3	4	4	2	5	2	3	3.0	3.20	-0.20	2
Traffic Safety	5	5	3	3	3	4	3	3	4	4	3	3.5	3.70	-0.20	1
Security	2	5	1	2	3	5	1	2	5	2	2	2.0	2.80	-0.80	3
Fatalities	5	2	4	5	4	3	2	1	3	2	2	3.0	3.10	-0.10	2

4. To assign a value to the cross-impact index of each interaction event, a pair was employed to calculate the coefficient value (CV) and the posterior probability (posterior Pi) by using Equations (1) and (2), respectively.

$$CV = |\text{cross-impact index}| + 1 \text{ if cross-impact index} > 0 \quad (1)$$

$$CV = 1/(|\text{cross-impact index}| + 1) \text{ if cross-impact index} < 0 \quad (2)$$

$$\text{Posterior } P_n \frac{CV^{*}\text{Initial } P_n}{1\text{-Initial } P_n + (CV^{*}\text{nitial } P_n} \quad (3)$$

When: Posterior P_n = Posterior Probability
Iniatial P_n = Initial Probability
CV: Coefficient value = Coefficient value

5. The Monte Carlo technique was used to generate 10,000 random numbers for 10,000 trials that were used to simulate a sequence of scenarios.

4. Results and discussion

Numbers are randomized by the Monte-Carlo technique using the Oracle© Crystal Ball 10,000 times. The resulting numbers corresponded to 26 scenarios, as shown in Table 5, from the total number of possible scenarios, 1,594,323 scenarios (3*3*3*3*3*3*3*3*3*3*3*3*3). The most likely event sequence scenario, which was scenario No.24 (sequence of events A3B3C3D2E2F2G3H3I3J2K2L2M2), had a frequency of occurrence equal to 1191, as shown in table 5. The occurrence of a random event image. It can be summarized as follows: gross domestic product (GDP) is poor, vehicle volume is high, travel distances are far, road conditions are moderate, weather is moderate, travel speed is moderate, special events are big, travel affordability is quite expensive, accessibility of the mobility system is moderate, travel safety is safe, comfort and convenience are moderate, and the overall situation of urban mobility is in moderate shape. This vision of the future is the result of a cross-impact analysis for these factors on the development and investment of urban mobility projects., as shown in Tables 5 and 6.

Table 5 The event sequence scenarios

Scenario No.	Event sequence scenario	Frequency of occurrence	Percentage
1	A1B1C1D1E1F1G1H1I1J1K1L1M1	335	3.35%
2	A1B2C1D1E1F1G1H1I1J1K1L1M1	662	6.62%
3	A1B2C2D1E1F1G1H1I1J1K1L1M1	953	9.53%
4	A1B2C2D1E1F2G1H1I1J1K1L1M1	44	0.44%
5	A2B2C2D1E1F2G1H1I1J1K1L1M1	606	6.06%
6	A2B2C2D1E1F2G1H2I1J1K1L1M1	238	2.38%
7	A2B2C2D1E1F2G2H2I1J1K1L1M1	985	9.85%
8	A2B2C2D1E1F2G2H2I2J1K1L1M1	208	2.08%
9	A2B3C2D1E1F2G2H2I2J1K1L1M1	284	2.84%
10	A2B3C2D1E1F2G2H2I2J1K1L1M2	25	0.25%
11	A2B3C2D1E1F2G2H2I2J1K1L2M1	263	2.63%
12	A2B3C2D1E1F2G2H2I2J1K1L2M2	296	2.96%
13	A2B3C2D1E1F2G2H2I2J2K1L2M2	70	0.70%
14	A2B3C2D2E2F2G2H2I2J2K1L2M2	55	0.55%
15	A2B3C2D2E2F2G3H3I2J2K1L2M2	213	2.13%
16	A2B3C2D2E2F2G3H3I3J2K1L2M2	760	7.60%
17	A3B2C2D2E2F2G2H2I2J2K1L2M2	430	4.30%
18	A3B2C2D2E2F2G2H2I2J2K2L2M1	194	1.94%
19	A3B2C2D2E2F2G2H3I2J2K2L2M1	39	0.39%
20	A3B2C2D2E2F2G2H3I2J2K2L2M2	329	3.29%
21	A3B2C3D2E2F2G2H3I2J2K2L2M2	443	4.43%
22	A3B2C3D2E2F2G3H3I2J2K2L2M2	67	0.67%
23	A3B2C3D2E2F2G3H3I3J2K2L2M2	125	1.25%
24	A3B3C3D2E2F2G3H3I3J2K2L2M2	1191	11.91%
25	A3B3C3D2E2F3G3H3I3J2K3L2M2	167	1.67%
26	A3B3C3D3E3F3G3H3I3J3K3L3M3	1018	10.18%
Number of simulations		10000	100.00%

Table 6 The result of event sequence scenario simulation

Event				Initial Prob.	Freq. of occurrence	Posterior Prob.
A	GDP	A1	Good	0.2	1994	0.20
		A2	Moderate	0.4	4003	0.40
		A3	Poor	0.4	4003	0.40
B	Vehicle volume	B1	Low	0.1	335	0.03
		B2	Average	0.4	4338	0.43
		B3	High	0.5	5327	0.53
C	Travel distance	C1	Short	0.1	997	0.10
		C2	Median	0.6	5992	0.60
		C3	Far	0.3	3011	0.30

Event				**Initial Prob.**	**Freq. of occurrence**	**Posterior Prob.**
D	Road condition	D1	Good	0.5	4969	0.50
		D2	Moderate	0.4	4013	0.40
		D3	Bad	0.1	1018	0.10
E	Weather	E1	Good	0.5	4969	0.50
		E2	Moderate	0.4	4013	0.40
		E3	Bad	0.1	1018	0.10
F	Travel Speed	F1	Fast	0.3	1950	0.20
		F2	Moderate	0.5	6865	0.69
		F3	Slow	0.2	1185	0.12
G	Special Events	G1	Small	0.2	3823	0.38
		G2	Median	0.4	2636	0.26
		G3	Big	0.4	3541	0.35
H	Travel time	H1	Short	0.2	2600	0.26
		H2	Median	0.3	3048	0.30
		H3	Long	0.5	4352	0.44
I	Affordability	I1	Inexpensive	0.3	3823	0.38
		I2	Acceptable	0.3	2916	0.29
		I3	Expensive	0.4	3261	0.33
J	Accessibility	J1	Good	0.4	4899	0.49
		J2	Moderate	0.5	4083	0.41
		J3	Poor	0.1	1018	0.10
K	Travel safety	K1	Very safe	0.4	6427	.
		K2	Safe	0.4	2388	0.24
		K3	Unsafe	0.2	1185	0.12
L	Comfort	L1	Good	0.3	4340	0.43
		L2	Moderate	0.5	4642	0.46
		L3	Poor	0.2	1018	0.10
M	Urban Mobility	M1	Good	0.4	4811	0.48
		M2	Moderate	0.5	4171	0.42
		M3	Poor	0.1	1018	0.10

This paper aimed to find the influence factors that affect urban mobility development, based on assumptions that were tested by applying cross-impact analysis to analyzes the interrelationship and the probability of these factors. From cross-impact analysis between factors affecting urban mobility and the likelihood of those factors affecting urban mobility development, it can be seen that those factors affect each other in a causal and consequential manner. That is when an event occurs, which will inevitably change the chance of occurrence of subsequent events. However, an event will occur in a way that promotes or refutes it depending on the future situation. Here, future events are presented randomly; that is, there are optimistic, most likely, and pessimistic scenarios, depending on a Monte Carlo randomized simulation of which events will occur. How the occurrence of these events might affect urban mobility is shown in Table 7.

Table 7 Perspective between the relationship of each factor from the simulation

Factors	**Accessibility**			**Travel safety**			**Comfort**			**Urban Mobility**		
Event	**Optimistic**	**Most likely**	**Pessimistic**	**Optimistic**	**Most likely**	**Pessimistic**	**Optimistic**	**Most likely**	**Pessimistic**	**Optimistic**	**Most likely**	**Pessimistic**
Accessibility												
Travel safety												
Comfort												
Urban Mobility												

Remake: good or safe moderate poor or unsafe

Model validation: If there is an increase in the public transport in the city, it will help to move the city more aggressively. By simulating the investment situation of public transport systems, both the bus system and the Paratransit system, it was found that the number of private vehicles decreased, as shown in Figure 3. Simulation showed that there was also a change in the number of trips per day with more investment public transport based on the data obtained to analyze cross-impact and simulate Monte Carlo results, as shown in Figure 4. Figure 4 shows that if the urban mobility is very good, it will produce effects for other factors related to urban mobility, such as a higher GDP, more accessibility to transportation systems, reduced travel time, safer travel, and more comfortable travel.

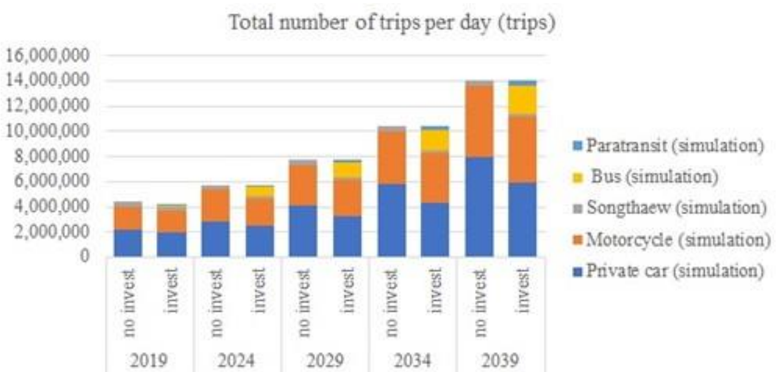

Figure 3 Shows change in number of trips per day (trips) by simulation scenario investment public transport

Factors	Event
	0.265007703
GDP (A)	MODERATE
Vehicle volume (B)	AVERAGE
Travel distance (C)	MEDIAN
Road condition (D)	GOOD
Weather (E)	GOOD
Travel Speed (F)	FAST
Special Events (G)	MEDIAN
Travel time (H)	MEDIAN
Affordability (I)	INEXPENSIVE
Accessibility (J)	GOOD
Travel safety (K)	VERY SAFE
Comfort (L)	GOOD
Urban Mobility (M)	GOOD

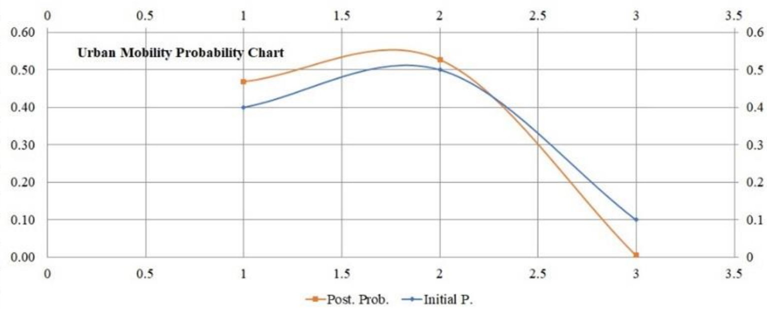

Figure 4 Results of the Monte Carlo simulation: case scenario investment public transport in Chiang Mai city

The results of the study concluded that accessibility factors that influence urban mobility had the highest probabilities because these are important factors when accessing the city's important resources and services (Sze, & Christensen, 2017). This is in accordance with the concept of transport infrastructure development by Dena Kasraian, Maat and van Wee (2019) that transport accessibility and policy on urban growth are key drivers of steady urbanization, and under the Covid-19 pandemic, urban accessibility has also affected urban mobility. Therefore, holistic access-based planning with a focus on sustainability and equity is the most suitable option of solutions to urban mobility problems and the impact on the quality of life of residents, as explored in the Brazilian context in the report issued by the National Association of Urban Transport Companies (Bracarense & de Oliveira, 2021).

6. Conclusion

This paper analyzes the factors influencing urban mobility, considering the interaction between factors and conditional probabilities. The analysis of the factors associating with urban mobility was under the techniques of EDFR and CIA while the collection of important data followed the EDFR technique. The examined factors and probable events for each item were identified by key informant interviews. The CIA method was used in the analysis to determine the relationships between the factors and events as well as the probability that those factors will contribute to the development of the mobility project in the city. The Monte Carlo technique was used with the use of a random range of numbers programmed to randomize the occurrence of those factors in the future. After that, the model was tested for functionality.

The study found that the top five factors affecting urban mobility are accessibility, travel safety, convenience, GDP, and vehicle volume, respectively. These factors were run through a simulation. The results obtained from the simulation experiment revealed that the model can point out a number of factors that affect the possibility of urban mobility in various situations. These key factors were applied in the model. The results showed that this model can determine the factors that affect the possibility of future development. And such a model could be a tool for planners and developers to prepare for future decisions. Urban mobility affects the accessibility of the urban mobility system, travel safety, and comfort in travel, as shown in Figure 2.

The Monte Carlo technique was applied to random future simulations. This resulted in 26 situations. The most probable chronology of Chiang Mai's urban mobility scenario is scenario 24, with a frequency of 1,191. This sequence is a relatively low GDP scenario with a lot of cars and a longer travel distance, road and weather conditions are quite good, vehicles can be driven at a low speed, there are large special events, travel times are longer, travel expense is higher, accessibility is pretty good, it is safe to travel, there is some convenience in traveling, and movement in the city is relatively flexible.

The change in the probability of an individual event is the result of the interaction of influencing factors. Events with a large number of related factors, such as vehicle volume and vehicle speed, showed greater probabilistic changes compared to other factors affecting the urban mobility in Chiang Mai identified in this study. It can be used as a variable in planning the throttling and speed control used in urban areas to support urban planning decisions and the development of urban infrastructure projects. Thus, application of the cross-impact methodology for urban mobility planning makes it possible to see the link between factors and the confidence values of each event. This is useful for urban planners and urban developers, who can apply it to each event when risk factors change and find ways to reduce the effects before investing in the implementation of the project.

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