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Path Analysis Model of Heavy-Duty Vehicle Safety for Road Environment Improvement and Accidents Prevention

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Abstract

The 2018 WHO report shows that Thailand has the highest road fatalities and injuries in Asia. This study uses 400 DBQ samples and near-miss data from ADAS and DMS in 246 heavy-duty vehicles to analyze risky driving behaviors from May to July 2022.The research aims to understand the causes of accidents by presenting a safety measurement model in logistics. Each dimension includes the indicators derived from the consensus of the experts, whose backgrounds are in logistics and safety from public and private entities, under the Delphi method. While the methods to evaluate opinions vary upon researchers, without a fixed procedure, the most widely used method is the Delphi method. With the Kendall's W of 0.402 and p-value less than 1, the study has found that there are four dimensions with 15 factors and 55 indicators explaining the topic. The four dimensions: driver behaviors; unsafe road environments; vehicles; and near-miss events, were tested for their correlations among the variables that relate to road accidents with path analysis, a statistical tool to analyze correlations among variables. The result shows that the improvement in unsafe road conditions and driver behaviors is critical to reduce the road accidents in Thailand. Therefore, the path and correlation analysis enhance the understanding on the correlations of each factor. Moreover, the reliability test has found that the absolute fit indices, including the CMIN/DF of 1.26, RMSEA of 0.026, GFI of 0.97, AGFI of 0.95 and RMR of 0.024, are in satisfactory level as well as the incremental fit indices with the NFI of 0.98, CFI of 0.99, TLI of 0.98 and IFI of 0.99. Therefore, the study on the drivers' behaviors unsafe road environments, vehicles and near-miss events in this research, together with the proposed model, enable responsible authorities to promote road safety by improving environments and driver behaviors as well as planning the strategy to reduce accidents nationwide.

Keywords: Path analysis, Heavy-duty vehicle safety, Road environment, Accidents prevention
Type of Article: Research Article

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ผ่านการรับรองคุณภาพจากศูนย์ดัชนีการอ้างอิงวารสารไทย (TCI.) อยู่ในกลุ่ม 2 สาขามนุษยศาสตร์และสังคมศาสตร์

โมเดลการวิเคราะห์เส้นทางความปลอดภัยของยานพาหนะหนักสำหรับการปรับปรุงสภาพแวดล้อมถนนและการป้องกันอุบัติเหตุ

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บทคัดย่อ

รายงานสถานการณ์โลกเกี่ยวกับความปลอดภัยทางถนนปี 2018 ขององค์การอนามัยโลก (WHO) ได้รายงานสถิติอุบัติเหตุทางถนนของประเทศไทย ที่มีจำนวนการเสียชีวิตและบาดเจ็บที่สูงกว่าประเทศอื่นในภูมิภาคเอเชีย การศึกษานี้วิเคราะห์พฤติกรรมที่เสี่ยงต่อการเกิดอุบัติเหตุโดยใช้ตัวอย่าง DBQ 400 ตัวอย่าง และข้อมูลใกล้พลาดตั้งแต่เดือนพฤษภาคมถึงกรกฎาคม 2022 ซึ่งรวบรวมจากระบบ ADAS และ DMS ในยานพาหนะหนัก 246 คัน งานวิจัยนี้มีวัตถุประสงค์เพื่อแก้ไขปัญหาดังกล่าว โดยใช้เทคนิค Del-phi method เพื่อหาฉันทามติจากผู้เชี่ยวชาญทางด้านการขนส่งและความปลอดภัยในการขนส่งทั้งหน่วยงานภาครัฐและเอกชน ขั้นตอนการประเมินความคิดเห็นอาจแตกต่างกันขึ้นอยู่กับนักวิจัย โดยไม่มีขั้นตอนที่แน่นอน แต่วิธีการประเมินที่ได้รับความยอมรับมากที่สุดคือวิธี Del-phi เพื่อกำหนดตัวชี้วัดที่สามารถใช้ในการประเมินมิติที่ซับซ้อนด้านความปลอดภัยในการขนส่ง พบว่า ประกอบไปด้วย 4 มิติ 15 องค์ประกอบ 55 ตัวชี้วัด ซึ่งมีฉันทามติที่ระดับสูงโดยมีค่า Kendall’s W=.402 and $P < 0.001$ จากนั้นได้ทำการหาค่าความสัมพันธ์ทางสถิติระหว่าง ตัวแปรด้านพฤติกรรมคนขับ สภาพแวดล้อมที่ไม่ปลอดภัยบนท้องถนน ยานพาหนะ และเหตุเกือบเกิดอุบัติเหตุ ด้วยเทคนิคการวิเคราะห์เส้นทาง (path analysis) ซึ่งเป็นเครื่องมือสถิติที่ใช้ในการวิเคราะห์ความสัมพันธ์ระหว่างตัวแปร เพื่อให้เข้าใจและวิเคราะห์ความสัมพันธ์ของตัวแปรต่าง ๆ ที่เกี่ยวข้องกับอุบัติเหตุทางถนน งานวิจัยนี้ชี้ให้เห็นว่าการปรับปรุงสภาพแวดล้อมทางถนนที่ไม่ปลอดภัยและพฤติกรรมขับขี่ของผู้ขับขี่เป็นสิ่งสำคัญในการลดอุบัติเหตุทางถนนในประเทศไทย การวิเคราะห์เส้นทางและวิเคราะห์ความสัมพันธ์ระหว่างตัวแปรช่วยให้เราเข้าใจว่าองค์ประกอบต่าง ๆ มีความสัมพันธ์กันอย่างไร ผลการตรวจสอบความน่าเชื่อถือ พบว่า Absolute fit ประกอบไปด้วย CMIN/DF = 1.26 RMSEA = .026 , GFI = .97 , AGFI = .95 , RMR = .024 และ Incremental fit ประกอบไปด้วย NFI = .98 , CFI = .99 , TLI = .98 , และ IFI = .99 ทั้งหมดอยู่ในระดับดี โดยการศึกษา แบบจำลองนี้มีประโยชน์ต่อหน่วยงานที่เกี่ยวข้องในการปรับปรุงสภาพแวดล้อมที่ไม่ปลอดภัยและพฤติกรรมของผู้ขับขี่เพื่อการวางแผนเชิงกลยุทธ์และการจัดการอุบัติเหตุที่อาจเกิดขึ้นในแต่ละพื้นที่ของประเทศ

คำสำคัญ: การวิเคราะห์เส้นทาง, ความปลอดภัยของยานพาหนะหนัก, สภาพแวดล้อมถนน, การป้องกันอุบัติเหตุ
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ผ่านการรับรองคุณภาพจากศูนย์ดัชนีการอ้างอิงวารสารไทย (TCI.) อยู่ในกลุ่ม 2 สาขามนุษยศาสตร์และสังคมศาสตร์

1. Introduction

The growth in inland logistics leads to the expansion in manufacturing and surge in e-commerce with the value of e-commerce business at THB 4,013.40 billion in 2021, increased from THB 3,782.17 billion in 2020 or 6.11%. The loosened restrictions of cross-border trade also result in the expansion of trade volume to THB 1,488.47 billion in 2021, increased from THB 1,146.92 billion in 2020 or 29.78%. The growth in inland transport and higher demands of HDV increase traffic density and the risk of road accidents, which are critical causes of fatalities, injuries, and disabilities. from a public health perspective. While the causes of accidents are varied, they are mostly attributed to drivers and their behaviors, with direct correlation to road users, road conditions and environments. (Domenichini et al., 2019) Another major cause is found in the environments that can lead to the risk of collisions because road conditions and dynamic information of traffics allow driver to effectively assess and (Wang et al., 2020) avoid or mitigate damages from the accidents. The analysis of driver behaviors describes how the drivers use their vehicles in certain environments as well as their behaviors and route selections for safer drive (Elamrani Abou Elassad et al., 2020). An improvement in risky driving encourages road safety and enables the drivers of heavy duty vehicles (“HDVs”) (Mase et al., 2020) to become more cautious on safety, leading to higher efficiency in delivery and energy consumption. Furthermore, unsafe environments and congestion, frequently found in urban areas, lead to accidents with HDVs. In addition, a long trip and bad traffic caused by congestion negatively impact mental health of the drivers, inducing the behaviors of swift lane changing or swerving as well as the risk of accidents (Davoli et al., 2020) caused by collisions.

Aside from. Unsafe environments and poor road conditions increase the risks in loss control of vehicles where poor visibility due to weather conditions and insufficient illumination impair drivers’ vision, affecting the safety of HDVs.

To address the issue, the study intends to analyze the correlations among variables with path analysis, a statistical method to analyze structural network among variables, providing better understanding on the interaction among variables within the system as well as their impacts and correlations. Path analysis can be applied in studying and analyzing correlations among dimensions: driver behaviors; unsafe road environments; and vehicles, with the near-miss events added as another dimension to build a model.

2. Research’s objective

1. To identify the consensus from the experts in transportation by using the Delphi Method

2. To analyze correlations among dimensions by path analysis

3. To form a foundation of accident management strategies through. the

mprovement in unsafe environments and driver behaviors.

3. Conceptual framework

The data analysis tool was designed after the final 55 variables were concluded by the ratings on the five-point Likert scales from the experts under the Delphi method. The researchers calculated the item-objective congruence, where the data was deemed convergent and accurate when the value was 0.5 or above. Then, the researchers validated the data stability with Cronbach's Alpha. with the acceptance criteria of the minimum of 0.7. Afterwards, the researchers requested 400 samples of HDV drivers selected under the Yamane Taro equation to answer anonymously. The researchers compiled data from 4 sources: the data on the accidents during 2019-2021 from Department of Land Transport; the data on the accidents during 2019-2021 from Ministry of Transport; the data on the current status of Asian Highway in Thailand from Department of Land Highways; and the data on the near-miss events during May – July 2022 from the ADAS and DMS devices installed on 246 HDVs. Then, the researchers prepared the data with sufficient suitability for spatial analysis as shown in the conceptual framework in Figure 1.

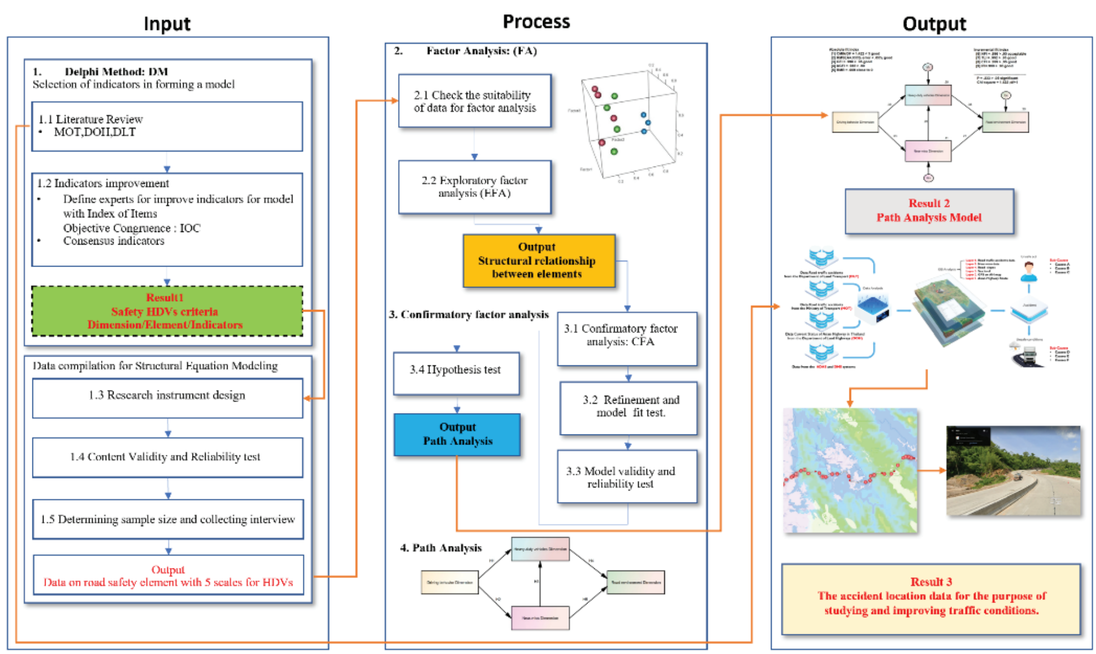

Figure 1 Conceptual framework for methods

The Global status report on road safety 2018 by WHO estimates that there are more than 22,000 road fatalities a year, which can be reduced by strict enforcement of law and traffic regulations. To improve road safety, Thailand can implement global practices such as road safety management, safe road and mobility, safety in vehicles and road users as well as vehicle accident responses. The practices also include the management of speeding, compliance with traffic regulations and other factors that lead to accidents in vehicles. including HDVs.

4.1 Driver behaviors

The study on driver behaviors has found that driving attitude is the major cause of accidents because it leads to a loss of concentration and negligence. Personal attributes also play an important role in minimizing accidents. Inducing behaviors such as disregarding traffic regulations, aggressive driving and using a phone while driving. In 2017, Thailand suffered from productivity loss due to the inland accidents for THB 121 billion, equivalent to 0.8% of the country's GDP (Chantith et al., 2021).

4.2 Driver fatigue

Accidents are largely caused by driving above the speed limit. Above speed limit, accumulated driver fatigue and unsafe environments. Therefore, strict implementation of laws to reduce road accidents and losses is necessary. Moreover, the causes of accidents should be analyzed for suitable planning and execution of measures to prevent accidents efficiently. This study proposes that accumulated experiences, knowledge on safety and improvements in working and sleeping conditions will significantly reduce the errors caused by frustrations in the HDV drivers (Shams et al., 2021). To address the issue, the study analyzed the correlations among variables with path analysis, a statistical method to analyze structural network among variables, providing better understanding on the interactions among variables within the system as well as their impacts and correlations. In this research, path analysis was applied in studying and analyzing correlations among the dimensions of driver behaviors, unsafe road environments, vehicles and near-miss events. Through the literature reviews, the researchers have found that the existing studies on the road safety model generally focus on driver behaviors, unsafe roadway environment and types of vehicles. Still, there is limited research pointing at the near-miss events, while the events can alert drivers or road users to realize potential risks of accidents and remind the drivers to drive safely. In addition, the near-miss experiences enable the drivers to improve their driving behaviors by adjusting the drive upon the conditions of roads and vehicles now.

5. Methodology

5.1 Research hypothesis

Hypothesis 1: There is a direct effect of the "Driver Behaviors Dimension" on the "Heavy-duty vehicles Dimension."

Hypothesis 2: There is a direct effect of the "Driver Behaviors Dimension" on the "Near-miss Dimension."

Hypothesis 3: There is a direct effect of the "Near-miss Dimension" on the "Heavy-duty vehicles Dimension."

Hypothesis 4: There is a direct effect of the "Heavy-duty vehicles Dimension" on the "Road Environment Dimension."

Hypothesis 5: There is a direct effect of the "Near-miss Dimension" on the "Road Environment Dimension."

All hypotheses are shown in Figure 2.

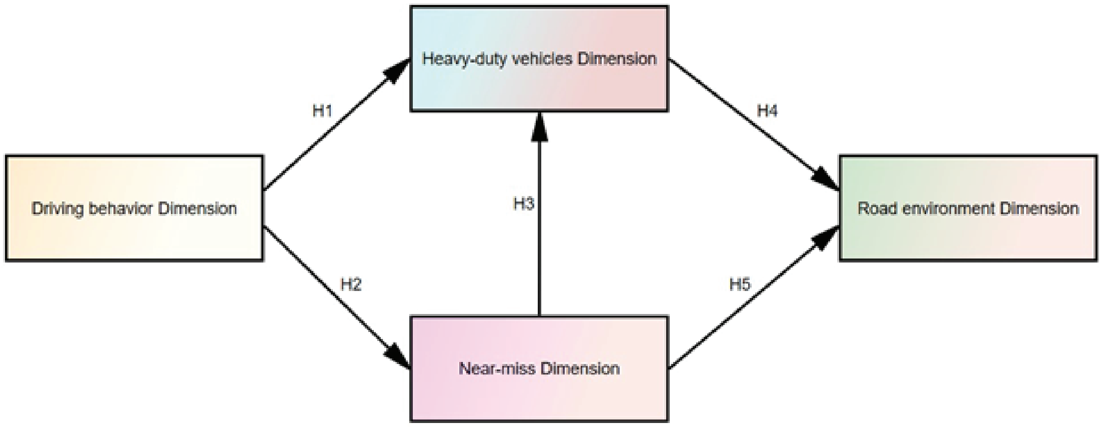

Figure 2 Research hypothesis model

5.2 Delphi method

The Delphi method compiles and improves the opinions from experts to build a consensus. It is applied in the selection of indicators in numbers of studies, with an iterative process. to conclude an agreement. During the process, the expert is required to adjust the opinions to align with the group average (Perveen et al., 2019). While the method to assess the opinions is varied, the most widely accepted method is the Delphi method (Zhu et al., 2023). Under the method, the experts are selected from their capabilities to respond to the questionnaire (Okafor et al., 2023), limited only to the questions on their expertise (Taghouti et al., 2022). This study analyzes the variables with the Delphi method and the observed variables obtained. From the literature reviews, with the structural question. The overall process is described below.

5.2.1 Establishing expert panel

As the appropriate number of experts under the Delphi method ranges between 7 to 15 (Matemane et al., 2022), this study selected 13 experts in logistics and related safety by purposive sampling from public and private entities as well as academia to maintain the expected qualifications. The experts came from, namely, the department of land transport. The department of highways. a large freight vehicle manufacturer and a management level responsible for safety in a logistic company. Therefore, the experts fully had expertise. and understanding the subject.

5.2.2 Delphi procedure & consensus criteria

After the acknowledgement of the experts, the researchers distributed the first questionnaire, consisting of the indicators derived from the literature reviews, for the item-objective congruence where the experts evaluated its validity and suitability to build the Correlation Safety HDVs Model ("CSHM"). The experts were then inquired to rate each item from -1 to +1, where the score was preferred when it was close to 1 with the acceptance criteria of 0.05 or above. In case the indicator scored less than or equal to 0.05, it would be revised. After reviewing the scores, the researchers redistributed the questionnaire with only the indicators meeting the criteria from the first round. This time, the experts rated the indicators from 1 to 5 with the five-point Likert scales, where "5" referred to the "most important" and "1" refers to the "least important". By using the scales, subjective judgments were quantified for further analysis and interpretation of the data. The criteria to conclude the consensus were: the median of 4 or above; the interquartile range of 1 or below; the standard deviation below 1; and the Kendall's W of 0.5 or below (Ritmak et al., 2023).

5.3 Path analysis

Path analysis is adopted to study the influences of observed variables to find direct and indirect causal relationships between variables. Path analysis indicates the details of relations between two variables and weighs the correlations as a path diagram (Jomnonkwao et al., 2020). In this study, it was deployed to assess variables on safety in risky road behaviors.

5.3.1 Consensus procedure & design of research tool

This study used 400 DBQ samples and the researcher's collected data from 4 sources with the data on the accidents during 2019-2021 from Department of Land Transport, the data on the accidents during 2019-2021 from Ministry of Transport, the data on the current statusof Asian Highway in Thailand from Department of Land Highways and the data on the near-miss events during May – July 2022 from the ADAS and DMS devices installed on 246 HDVs. Subsequently, the researchers prepared the data for spatial analysis.

5.4 Data analysis

The data analysis tool was designed after the final 55 (Pumpugsri et al., 2023) variables were concluded by the ratings on the five-point Likert scales from the experts under the Delphi method. The data was deemed convergent and accurate when the value of the item-objective congruence was 0.5 or above. Then, the researchers validated the data stability with Cronbach's Alpha, with the acceptance criteria of the minimum of 0.7. In general, Cronbach's Alpha measures the reliability of a scale, indicating the level of relations among items in a group. In this research, items referred to the items listed on the Liker-scale questionnaire. Afterwards, the researchers provided the questionnaire to 400 samples, who were the HDVs drivers selected under the Yamane Taro equation, to answer anonymously.

6. Results

6.1. Reliability of delphi method

The analysis in Figure 3 showed that the opinions from the 13 experts have the item-objective congruence value of 0.45, standard deviation of 0.41 and median of 4.8 for each variable. As all variables met the acceptance criteria, with the item-objective congruence value equaled to or less than 1, the median of 4 or above and the standard deviation less than 1, it could be interpreted that the opinions from the experts were aligned significantly [44]. As the Kendall's W also ranged between 0.30 and 0.50, the concordance in the experts' opinions was statistically significant as p was less than 0.001 (Uysal Toraman et al., 2023). As a result, the opinions of the experts were concluded as a consensus for all indicators, which was critically significant in this study.

6.2. The correlation safety HDVs model

The Correlation Safety HDVs Model was conducted by path analysis on the correlations among the variables regarding HDVs from four dimensions as follows.

6.2.1 Driver behaviors dimension

HDV driver behaviors refer to the method and guidance on controlling vehicles that impact the safety of drivers, road users and environments. As HDV plays an important role in logistics, the drivers should bear responsibilities in minimizing the impacts of road safety on other road users. The driver behavior dimension or DBDm consists of five factors as below.

1. High-speed driving (HSD): the factor refers to unsuitable speeding that may lead to more dangers when compared with the normal drive.

2. Violation of Traffic Laws (VTL): the factor refers to disregards of traffic laws and regulations that may cause accidents and losses in property. while inducing safety issues on others.

3. Driver fatigue (DF): the factor refers to fatigue or drowsiness in drivers that may impact driving, controlling and decision-making capabilities. Since it increases the risk of accidents, drivers should have adequate. rest when feeling tired to prevent related risks.

4. Road rage driving (RRD): the factor refers to aggressive driving. and disregards traffic regulations that lead to the accidents. Therefore, the behaviors should be improved to comply with traffic regulations and have respect. to other drivers.

5. Driving without concentration (DWC): the factor refers to the state when a driver does not concentrate, leading to delays in response. and risk of accidents. Hence, the drivers should constantly focus on their drive, without any distraction during the course.

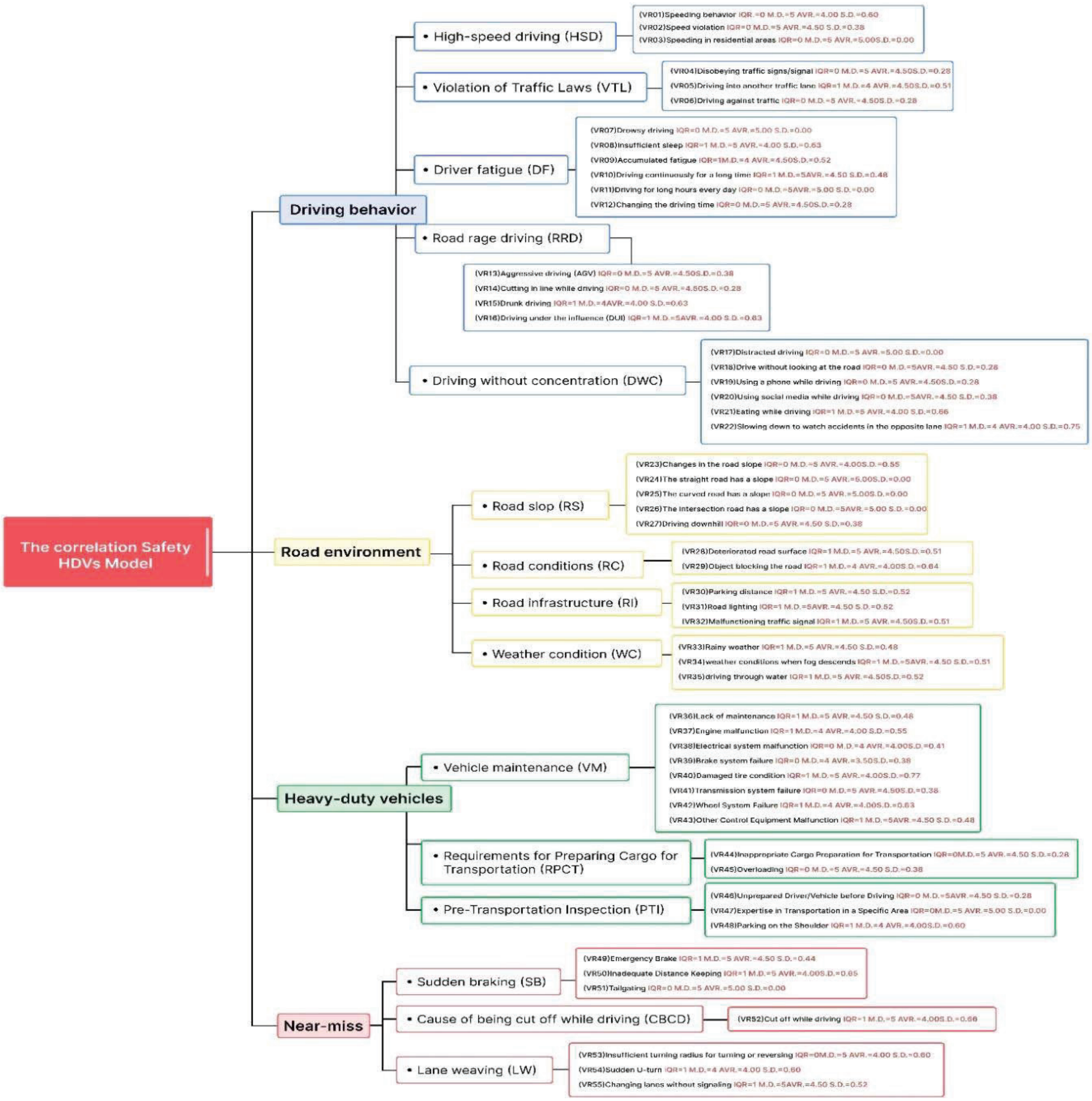

Figure 3 Delphi results.

6.2.2 Road environment dimension

Road environment dimension or REDm refers to certain conditions of roads and environments that affect safety in driving. The road environment includes composites such as road width, parking areas and traffic signals. As a result, road environments are crucial to maintain driving safety.

6.2.3 Heavy-duty vehicles dimension

The heavy-duty vehicles dimension or HDVDm is considered logistics by HDVs share the risk on safety; therefore, the drivers should comply with the laws and related safety standards. For example, periodic maintenance and the practice on wearing protective equipment should be regularly conducted.

To minimize the risk in logistics, the HDV drivers should be proficient and experienced in both driving and crisis management.

6.2.4 Near-miss dimension

Near-miss events are the events that resemble accidents. accidents, with no collision or loss occurring. The events are in the near-miss dimension or NMDm because they can function as alerts on the risk of accidents and enable road users to realize the importance of traffic regulations and road safety.

6.3 Reliability and sampling adequacy results

The research deployed the questionnaire to 400 samples, who were required to pass the test and examination on specific knowledges on HDV driving, possess the HDV driving license issued by Department of Land Transport in Thailand and equip with experiences in driving HDV.

Prior to conducting factor analysis, the researchers analyzed the validity of the data set with structural equation modeling and found Cronbach's Alpha of 0.92, passing the acceptance criteria of 0.70. Therefore, the questionnaire and variables employed in the research were significantly valid. Next, the Kaiser-Meyer-Olkin (“KMO”) and Bartlett's (“BT”) test showed that the KMO value was 0.88, which was higher than 0.50 or the acceptance criteria. Moreover, the BT value was 0.00, less than 0.05, meeting the acceptance criteria. With satisfactory results that all variables were highly suitable for factor analysis, the researchers then proceeded to exploratory factor analysis.

6.4. Exploratory factor analysis

The researchers conducted exploratory factor analysis or EFA on 15 factors and indicators as shown in Figure 3. During the process, the researchers recategorized the variables as follows: VR01-VR03 were grouped as HSD; VR04-VR06 were grouped as VTL; VR07-VR12 were grouped as DF; VR13-VR16 were grouped as RRD; VR17-VR22 were grouped as DWC; VR23-VR27 were grouped as RS; VR28-VR29 were grouped as RC; VR30-VR32 were grouped as RI; VR33-VR35 were grouped as WC; VR36-VR43 were regrouped as VM; VR44-VR45 were grouped as RPCT, VR46-VR48 were grouped as PTI; VR49-VR51 were grouped as SB, VR52 was labelled as CDCB and VR53-VR55 were grouped as LW accordingly. The researchers then extracted the factors with principal component analysis, which only the factors with eigenvalue above 1 to be remained. Next, the researchers rotated the factors with varimax rotation and found the commonalities value and factor loading of all variables were above 0.50. Therefore, all variables were congruent and suitable for factor analysis as shown in Figure 4. On the dimension, the experts recommended to categorize all 15 factors into four dimensions for EFA: the factor of HSD, VTL, DF, RRD and DWC were categorized into the DBDm; the factor of RS, RC, RI and WC were categorized into the REDm; the factor of VM, RPCT and PTI were categorized into the HDVDm; and the factor of SB, CBCD and LW were categorized into the NMDm.

Table 1 Confirmatory Factor Analysis - Factor Loading Statistics.

Dimension	The Standardized Factor Loading (*Li*)					Hypothesis Testing			
	Element	DBDm	REDm	HDVDm	NMDm	Estimate	S.E.	C.r.	p
DBDm	HSD	0.83				0.99	0.04	22.79	***
	VTL	0.9				1.01	0.04	22.79	***
	DF	0.9				0.92	0.05	20.58	***
	RRD	0.95				1.03	0.04	24.75	***
	DWC	0.7				0.83	0.05	15.56	***
REDm	RS		0.97			0.95	0.02	61.24	***
	RC		0.99			1.06	0.02	61.24	***
	RI		0.8			0.58	0.02	26.04	***
	WC		0.68			0.53	0.03	18.20	***
HDVDm	VM			0.75		0.95	0.07	12.86	***
	RPCT			0.83		1.05	0.08	12.86	***
	PTI			0.85		1.07	0.08	13.38	***
NMDm	SB				0.78	1.11	0.09	12.66	***
	LW				0.78	1.36	0.11	12.59	***
	CBCD				0.68	0.73	0.06	12.59	***

At first, exploratory factor analysis was conducted to reduce the number and examine suitability of the variables with an aim to confirm structural correlations among the variables in each group. Nevertheless, the analysis was insufficient to test the hypotheses related to structural correlations among the variables. Therefore, confirmatory factor analysis was introduced to the data, derived from exploratory analysis and proceeded by the AMOS program, to verify the correlations. The result in Table 1 showed that all factors in model-testing by confirmatory factor analysis are all statistically significant (***), aligned with the category in the exploratory factor analysis. When the composite reliability value was one or above, an indicator was regarded as suitable to represent a dimension. On the other hand, when the composite reliability value was less than one, the indicator was regarded as unsuitable to represent a dimension. The result showed that the first indices consisting of the. CMIN/DF of 1.26 implied the model fit with all statistical data. The RMSEA of 0.026, GFI of 0.97, AGFI of 0.95 and RMR of 0.024 could be interpreted as all statistical data were at a satisfactory level. were at a satisfactory level for the first group, similar to the second group with the P Chi-square of 0.07. The second group included the NFI of 0.98, CFI of 0.99, TLI of 0.99a and IFI of 0.99. Therefore, the model was concluded to be suitable with statistical data. The confirmatory factor analysis of the CSHM to four dimensions and the analysis from four dimensions to the factors present satisfactory results with the average variance extracted above 0.5 and critical ratio above 0.7 or the acceptance criteria. The model showed sufficient accuracy and validity of the indicators in all factors and dimensions as depicted in Figure 4 and Table 2.

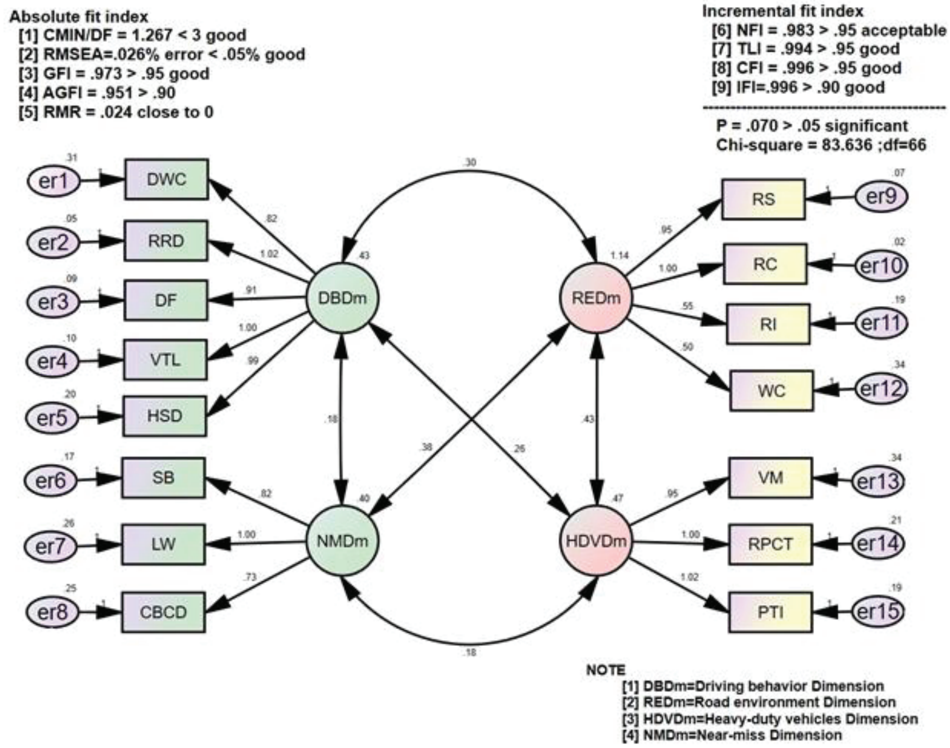

Figure 4 The interrelation among the four dimensions

Table 2 The Correlation Safety HDVs Model: CSHN

Dimensions/Element			*Li*	Li^2	e_i	C.R.	AVE.	CA.
DBDm	--->	HSD	0.83	0.68	0.32	0.93*	0.86*	0.93*
	--->	VTL	0.90	0.80	0.20			
	--->	DF	0.90	0.81	0.19			
	--->	RRD	0.95	0.90	0.10			
	--->	DWC	0.70	0.49	0.51			
REDm	--->	RS	0.97	0.94	0.06	0.92*	0.87*	0.92*
	--->	RC	0.99	0.99	0.01			
	--->	RI	0.81	0.65	0.35			
	--->	WC	0.68	0.46	0.54			
HDVDm	--->	VM	0.75	0.56	0.44	0.85*	0.81*	0.83*
	--->	RPCT	0.83	0.69	0.31			
	--->	PTI	0.85	0.72	0.28			
NMDm	--->	SB	0.78	0.61	0.39	0.79*	0.74*	0.79*
	--->	CBCD	0.68	0.46	0.54			
	--->	LW	0.78	0.60	0.40			

6.4.1 Research Hypothesis Testing

The Pearson correlation coefficient of each variable showed moderate correlations in all pairs of variables. Among the variables, the highest correlation was found in the Heavy-duty Vehicles Dimension and Road Environment Dimension with the r value of 0.488. The second highest correlation was found in the Driver Behavior Dimension and Heavy-duty Vehicles Dimension with the r value of 0.468. The third highest correlation was found in the Road Environment Dimension and Near-miss Dimension with the r value of 0.418. The fourth highest correlation was found in the Heavy-duty Vehicles Dimension and Near-miss Dimension with the r value of 0.381. Lastly, the Driver Behavior Dimension and the Near-miss Dimension had the r value of 0.327. In summary, all pairs of variables had positive correlations at the significance level of 0.01. As a result, all pairs of variables could be used to conduct path analysis to improve the behaviors of HDV drivers, according to the objective of this study. The result in Table 3 showed the research hypotheses.

Table 3 Results from the verification of research hypotheses.

Hypothesis	Pathway			Estimate	S.E.	C.R.	*p*	Results
H1	DBDm	-->	HDVDm	0.38	0.05	8.53	***	Accepted
H2	DBDm	-->	NMDm	0.33	0.04	6.91	***	Accepted
H3	NMDm	-->	HDVDm	0.26	0.06	5.68	***	Accepted
H4	HDVD	-->	REDm	0.39	0.06	8.51	***	Accepted
H5	NMDm	-->	REDm	0.27	0.07	6.00	***	Accepted

Hypothesis 1: the positive correlation between the DBDm and HDVDm was confirmed. As the path analysis of the model showed that standardized beta (ß) was statistically significant (Hypothesis 1: ß = 0.38 S.E. = 0.05 C.R. = 8.53). The correlation between the DBDm and HDVm could be explained that proper driver behaviors correlated with the logistics by HDV, meaning that an improvement in driver behaviors led to higher efficiency and safety in logistics by HDVs. Also, the behaviors to reduce energy consumption and carbon emission in logistics resulted in higher efficiency in the use of natural resources.

Hypothesis 2: the positive correlation between the DBDm and NMDm was confirmed due to the standardized beta (ß) that was statistically significant (Hypothesis 2: ß = 0.33 S.E. = 0.04 C.R. = 6.91). The correlation between the DBDm and the NMDm could be described that proper driver behaviors correlate with the near-miss events. Therefore, the improvement in driver behaviors reduced the near-miss events. As the near-miss events could also be adopted as alerts for the drivers to realize associated risks and driving issues, by minimizing the near-miss events, the risk of accidents would decrease, increasing driving safety.

Hypothesis 3: the positive correlation between the NMDm and HDVDm was confirmed due to the statistically significant standardized beta (ß) (Hypothesis 3: ß = 0.26 S.E. = 0.06 C.R. = 5.68). The correlation between the NMDm and HDVDm implied that the less frequent the near-miss events occurred, the higher efficiency and safety in the logistics by HDV. As the near-miss events conveyed the signals to drivers to realize and become cautious on the driving environments as well as their behaviors, they increased safety and reduced the risk. of accidents in logistics. Therefore, compliance and safe driving habits were important to reduce the near-miss events and increase safety in the logistics by HDV.

Hypothesis 4: the positive correlation between the HDVDm and REDm was confirmed by path analysis with the standardized beta (ß) that was statistically significant (Hypothesis 4: ß = 0.39 S.E. = 0.06 C.R. = 8.51). The correlation between the HDVDm and the REDm showed that the logistics by HDV related with the environment. Driving well-maintained vehicles. and improvement in road conditions could increase safety and efficiency in logistics. In contrary, inappropriate road conditions might cause the risk of accidents, interruption in logistics and other issues on the delays in delivery.

Hypothesis 5: the positive correlation between the NMDm and REDm was confirmed through path analysis with standardized beta (ß) that was statistically significant (Hypothesis 5: ß = 0.27 S.E. = 0.07 C.R. = 6.00). The correlation could be interpreted that the decline of near-miss events might have a positive impact on the safety and efficiency in logistics as proper conditions of roads could reduce the near-miss events and accidents while increasing efficiency in the logistics by HDV. Poor road and weather conditions might increase the accidents in the logistics by HDV, as shown in Figure 5.

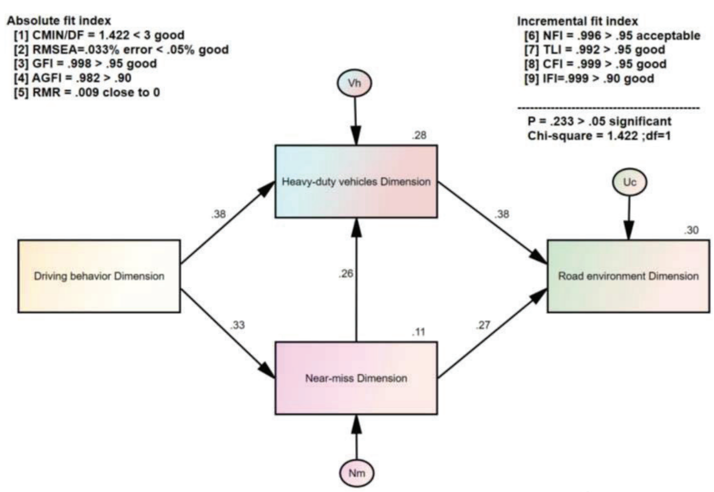

Figure 5 Path Analysis Results. CMIN/DF=1.42 RMSEA=0.033 GFI=0.99 AGFI=0.98 RMR=0.009 NFI=0.99 TLI=0.99 CFI=0.99 IFI=0.99 P=0.23 Chi-square=1.42 df=1

6.5 Traffic engineering

Traffic engineering relates to the design and plan of route, analysis and outline of traffic lights, planning and management of parking lots as well as other factors in relation to traffic management. The field of study plays an important role in building the environment for safe and efficient traffics upon the widely accepted standards. The focus on the road in an area development increases productivity and improves people's livelihood. Due to limitation on road design in some areas. traffic engineering must consider road alignment, sight distance, geometric design and intersection for the most convenient and safest road conditions.

6.5.1 Example data of mae sot border checkpoint

Inland transportation for export is critical to Thailand's economy due to the volume of cross-border trade to its GDP. Among the transactions, the exports through Mae Sot custom office are significant to the economy as they valued THB 134,856 million in the fiscal year of 2022. In parallel with the increasing value of exports during 2019-2021, accidents along the route occurred frequently, especially accidents involving HDV. The number of accidents, totalled up to 156 times with 58 injuries and 12 fatalities as shown in Table 4.

Table 4 Road Traffic Accident on Myanmar-Thai Bridge - Mae Lamao-Takn 2019-2021.

Road Traffic Accident	Uphill	Normal	Downhill	The injured	The deceased
Myanmar-Thai Bridge - Mae Lamao	15	27	39	28	10
Mae Lamao - Tak (Jct. R1/R12)	13	14	48	30	2
Total	**28**	**41**	**87**	**58**	**12**

7. Discussion and conclusion

This research found statistical correlations among the variables in driver behaviors, unsafe road environments, vehicles, and near-miss events with path analysis. Based on the 55 indicators and 15 factors that were grouped into four dimensions, the researchers confirmed the suitability of path analysis and the correlations among variables with the absolute fit indices and incremental fit indices. The researchers then examined the accuracy and validity of the model and found that all factors in all dimensions met the criteria, in line with the opinions of the experts. The hypothesis testing revealed that all four dimensions had positive correlations where a change in one dimension affected other dimensions. The consistency and validity of the model allowed users to comprehend the causes when proposing possible improvements in road environments from the aspect of traffic engineering and developing strategies for road safety. The accidents resulted in losses of life and properties as well as interruptions in the delivery of merchandise and instability in the businesses in Thailand. Among the accidents, 56% were caused by vehicles moving downhill. As the emphasis on safety is important to reduce accidents and increase the efficiency in exports, it is necessary to improve road structures, policies, and regulations to support and promote safety in logistics. While the analysis can be applied to improve the behaviors of HDV drivers and reduce the number of accidents, specific solutions must be customized to each unique topography. Moreover, public and private entities can utilize the data and the analysis to develop guidance guidance to increase road safety for safer driving environments in the future.

8. Recommendation

8.1 Recommendations for implementation

This research has an objective to find correlations among the variables related to road safety for HDVs through path analysis. The future research can implement structural equation modeling in model analysis to find correlations among the variables in complex traffics and measure the environments that cannot be measured directly to reach the conclusion for in-depth understanding in each dimension and factor.

8.2 Future research direction

The future research can compile data from the drivers of other types of vehicles for more diversity in the model. By doing so, the model will become more comprehensive to develop a criteria and guidance to improve road safety more efficiently.

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