An Analysis of Air Pollution Emission from Semi-Trailer Truck Transportation in Laem Chabang Municipality: A Structural Equation Modeling

Chalermpong Senarak

Department of Nautical Science and Maritime Logistics, Faculty of International Maritime Studies, Kasetsart University, Sri Racha Campus, No. 199 Moo 6, Sukhumvit Road, Tung Sukla, Sri Racha, Chon Buri 20230 Thailand

Corresponding author. E-mail address: chalermpong.s@ku.th

Received: 8 May 2019; Revised: 2 July 2019; Accepted: 9 July 2019

Abstract

The demand growth for container shipping in most countries increases the number of semi-trailer truck on the roads in port-proximate communities; consequently, the residents inevitably experience with air pollution and other externalities from STT transportation than ever. While a clear-cut solution has not been identified in theory, the current study attempted to narrow this gap by developing a holistic model focusing on all fundamental elements. To formulate the model, the relevant attributions were developed based on a literature review and used to develop a questionnaire survey randomly distributed to the respondents in the five communities in Laem Chabang municipality. Based on 414 responses, the structural equation modeling was adopted to analyze the relationships among 13 endogenous variables and 15 exogenous variables which were conceptualized based on the existing theories, and thereinafter adjusted based on the modification indices. The findings demonstrated that the STTs' safety standard had a greater impact on air pollution than that of STT drivers' behaviors, while road accidents and traffic congestion played an important role as an intermediary passing an indirect effect from its origins to air pollution emission. Therefore, the best solution was to eliminate the original sources of air pollution, but eradicating its intermediate sources would also help address the poor local air quality.

Keywords: Air Pollution Emission, Semi-Trailer Truck, Transportation, Laem Chabang Municipality, Structural Equation Modeling

Introduction

Truck transportation was a major contributor of air pollution and climate change. Annually, it emits a great deal of carbon dioxide (CO_2), nitrogen oxide (NO_X), carbon monoxide (CO), sulfur dioxide (SO_2), and other greenhouse gas emissions for approximately 14 percent of total anthropogenic emissions globally (Shaheen & Lipman, 2007; Dastoorpoor, Idani, Khanjani, Goudarzi, & Bahrampour, 2016). Statistically, one third of deaths from stroke, lung cancer, and heart disease are due to air pollution partially caused by the freight transport sector (World Health Organization, 2019). Over the past years, air pollution has continuously increased due to the growing number of semi-trailer trucks (STT) that are popularly used to transport the inbound and outbound containers between the in-dock facilities of seaports and off-dock storage yards, which mostly are located around the local communities (Davies, 2006; IBI Group, 2006; Yap, 2013). Recently, it was reported that the overwhelming use of containers that excess to port capacities caused a severe traffic congestion (World Health Organization, 2015) which was a substantial origin of road accidents, chronic stress and health problems in local communities locating around the major port areas of many countries, such as the Port of Klang (Maguire, Ivey, Golias, & Lipinski, 2010; Yap, 2013), Vancouver Port (Davies, 2006), the Port of Rotterdam (Zain et al., 2015), the Ports of New York (IBI Group, 2006), ports in Spain (Laxe, Bermú dez, Palmero, & Novo-Corti, 2016), ports in the UK (Asgari, Hassani, Jones, & Nguye, 2015), and ports in Japan (Motono, Kimito, Furuichi, & Suzuki, 2014).

Similarly in Laem Chabang municipality (LCM), STTs are popularly used for container haulage frequently found in communities locating around Laem Chabang Port - LCP (the largest container port on the eastern coast of Thailand), while the market share of other environmentally-friendly transport modes, such as rail and inland waterway transport, is very low (Thailand Board of Investment, 2016). Its popularity has rocketed since 2017 because of the emerging demand for container shipping by the new industries in Eastern Economic Corridor (EEC) areas covering three industrial provinces (i.e. Chachoengsao, Rayong, and Chonburi). The number of truck companies registered by the Department of Land Transport almost doubled from 45,855 in 2008 to 77,751 in 2015, while in the same period the number of STTs substantially rose from 105,593 to 187,219 (Department of Land Transport, 2015). Daily, more than 20,000 STTs are navigated on the routes among the LCP and its destinations in the hinterland, comprising 15 industrial estates in Chonburi (approximately 26% of the total industrial estates in Thailand), and many thousands of factories throughout the country (Industrial Estate Authority of Thailand, 2015). In a parallel to the boom in haulage business, the air quality in the sounding communities considerably degraded and as a consequence, the number of patients with acute upper respiratory tract infections in Chonburi doubled from 136,425 in 2013 to 399,733 in 2017 (Chonburi Provincial Public Health Office, 2019). In addition, the rate of STT-related accidents has continued to grow in LCM, with the death rate of local vehicle users increasing from 1,961 in 2014 to 2,020 in 2015 (Royal Thai Police, 2015).

Despite the fact that the causes of patients with acute upper respiratory tract infections in Chonburi were not clearly identified due to the medical privacy; however, the report of World Health Organization confirmed that a pack of negative externalities from freight transportation by road significantly aggravate air pollutants which caused many diseases (World Health Organization, 2019), while the dangerous behaviors of truck drivers and the vehicle deficiency were in the front rank of the vital causes of a road accident and a near miss (Royal Thai Police, 2015). Superficially, the health and environment problems from STT transportation were not relevant to the safety issue, but it was believed that road accidents and traffic congestion might interact with each other and subsequently impact air pollution emission and health problems. If this postulation was true, understanding the relationships among them would help the local policy makers and practitioners develop solutions and measures to effectively address the negative externalities of STT transportation.

Unfortunately, a review of relevant literature showed the scarce scholastic effort to take this critical issue into account. The research interest found in the previous literature was in the topics of the economic effects of truck transport (Yap, 2013; Zain et al., 2015), the environmental degradation from freight transport (Shaheen & Lipman, 2007; European Environment Agency, 2011; Laxe et al., 2016; Rajé , Tight, & Pope, 2018), the relationship between demographic or behavioral characteristics of truck drivers and accident (Elvik, Christensen, & Amundsen, 2004; Duke, Guest, & Boggess, 2010; Copsey et al., 2010; Ratanavaraha & Suangka, 2014), the relationship between drowsy driving and truck accident (Leechawengwongs, Leechawengwongs, Sukying, & Udomsubpayakul, 2006), the factors affecting traffic congestion and policy (Fei, Zhu, & Han, 2016; Wu, Chen, Ma, Bai, & Tang, 2017), the effects of bad weather on road accidents (Dastoorpoor et al., 2016), the management of overloading and road maintenance (Wen, Xuhong, & Jie, 2007; Tanaka, 2016; Rys, Judycki, & Jaskula, 2017), strategies to reduce accidents (Lan, Kanitpong, Tomiyama, Kawamura, & Nakatsuji, 2019), and the effects of traffic congestion on service provision (Maguire et al., 2010; Zain et al., 2015), etc. To the author's knowledge, there is no work developing a holistic model to analyze the interaction among the hazardous behaviors of STT drivers, safety standards of STT, air pollution, road accidents, and traffic congestion.

Hence, this study addressed the scarcity of the literature by analyzing how hazardous behaviors of STT drivers and safety standard of STT could cause road accidents, traffic congestion, and air pollution. Furthermore, the relationships among these three externalities were also investigated by using structural equation modeling (SEM). The relationships among variables consisted in the first SEM model were conceptualized based on the theories in the existing literature, while the data analyzed in this study was obtained from five communities of LCM, consisting of Ban Ao Udom, Ban Khao Numsub, Ban Sak Yai Chin, Wat Manorom, and Huai Lek. The criteria for selecting the study areas were: 1) the communities were located in freight transportation areas of the largest port of Thailand; 2) the number of deaths, injuries and patients from STT transportation gradually increased; 3) the dangers of container transportation have been continuously increasing due to the development of LCP and other industries under the EEC project (one of the largest national projects supporting the growth of Thailand Economy 4.0); and 4) the selected communities had common problems and situations experienced by many ASEAN and other ports and communities. Therefore, the research findings can provide useful information for local authorities, policy makers, truck operators and scholars not only in Thailand but also in other countries.

Methodology

Research Method and Data Analysis

The study started with a literature review of local and international studies and documents to: 1) identify the research problems and gaps, 2) determine research objectives and hypotheses, and 3) conceptualize the research framework. Following this, a questionnaire was developed and then used to conduct a roadside survey in the five communities by the author and research team. Each questionnaire was gathered immediately after the respondent had completed the questionnaire. After that its reliability (Cronbach's alpha > 0.7) was tested using the SPSS 23 before factor analysis was conducted in order to investigate the consistency between the survey data and the theoretical reference. Thereinafter, the relationship among variables were conceptualized based on the existing theories and then analyzed by using SEM technique in AMOS 21. Finally, the research findings were summarized and theoretical and practical implications were made for scholars, policy makers, and other practitioners.

Study Area

Laem Chabang municipality (LCM), as illustrated in Figure 1, is located in the East of Thailand and comprises 23 communities covering 109.65 square kilometers with approximately 19,453 residents (Laem Chabang Municipality, 2012). Although the size is relative small, LCM is one of the most important economic areas of Chonburi province as it is the production base for 3,786 factories in 15 industrial estates with investment value of USD 50,500 million (Thailand Board of Investment, 2016). Furthermore, the LCM is on the coastline of the East Gulf of Thailand and as a result it is the location of many important ports, such as Laem Chabang Port (LCP), SIAMCSP Seaport, Kerry Siam Seaport, Sriracha Harbor Port, PTT Sriracha Oil Terminal, and the Thai Oil Terminal. Almost 8 million containers are moved annually in LCM from more than 10,000 vessels to STTs for domestic transportation (United Nations Conference on Trade and Development, 2018). On average, there are 21,918 STTs per day navigating the roads in the communities located in LCM, including the Ban Ao Udom, Ban Khao Numsub, Ban Sak Yai Chin, Wat Manorom, and Huai Lek communities and affecting severely the living conditions of residents in terms of road accidents, traffic congestion, air pollution (Jongmeewasin, 2016), and ship-generated waste (Senarak, 2016).

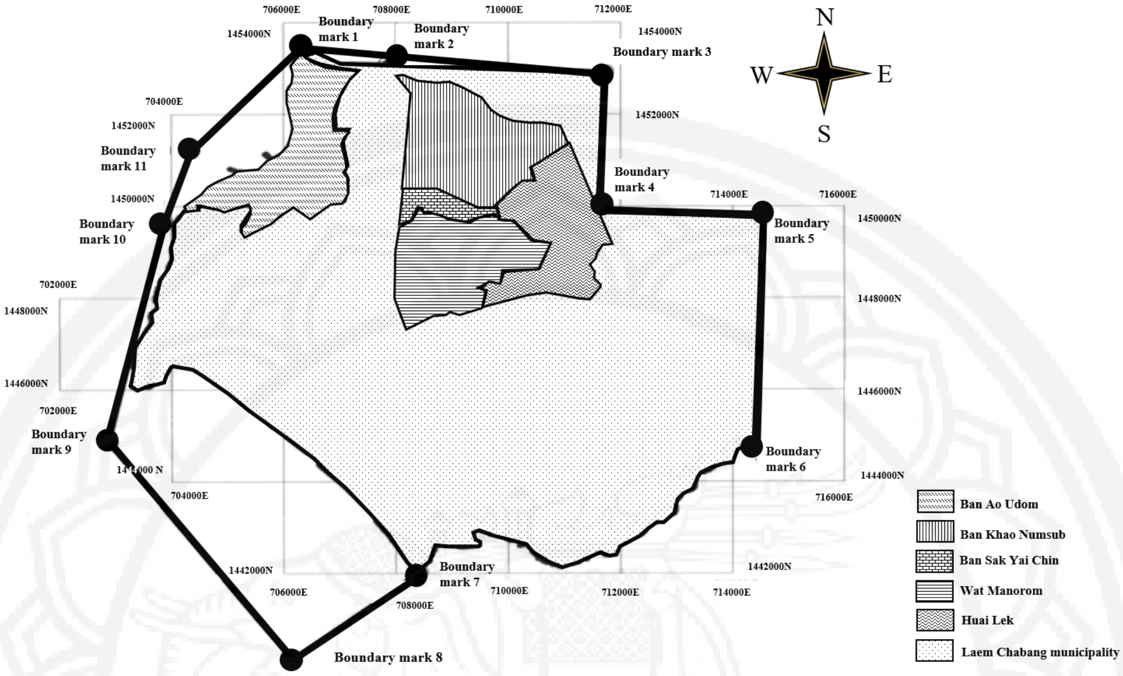

Figure 1 Study area in Laem Chabang municipality

Remark: Modified from image used by Laem Chabang municipality (2012)

Variable Development

Another contribution of this study was to exploratory develop variables reflecting the hazards of STT transportation which have not been described by other scholars. Basically, STT combines a tractor unit and one or more semi-trailers to carry container, which is attached to the tractor with a fifth-wheel coupling, with much of its weight borne by the tractor. STTs prevent the falling of a container from the trailer by locking twistlock device into the corners of the container. The containers are normally loaded with consumable cargoes for international trade; hence, the STT drivers generally drive long distances to pick up the shipment throughout the trip. With this reason, the STT drivers are expected to be trained regarding driving skills and regulations and responsible for many duties that relatively different from the drivers of general trucks. Based on the author's field observations in LCM and the information in accident reports of Royal Thai Police (2015), the author developed ten original variables to represent hazards of STT transport which were classified into two main groups: 1) the dangerous behaviors of STT drivers; and 2) safety standard of STTs, as described in Table 1.

Table 1 Hazardous characteristics in STT transportation

Types of Danger		Abbreviation	Description
Dangerous behaviors of STT drivers;	Violation of speed limit	Violation	The driver intentionally or unintentionally exceeds 45 km/h imposed by government agencies for a truck speed limit in Laem Chabang Municipality area).

Table 1 (Cont.)

Types of Danger		Abbreviation	Description
	Immediate lane changing	Lane	The driver immediately shifts or switches lanes without giving a turning signal to warn the other road users.
	Truck driver losing control	Control	The driver cannot control the truck in a safe manner while passing through a community due to the mechanical failure, physical disabilities, and mental illness.
	Unsafe parking	Parking	Unreasonable parking of vehicle on the shoulder, in a safety zone, or other parts of the road due to taking a short nap, washing vehicle, or other illogical reasons.
	Truck driver drowsiness	Drowsiness	The driver feels sleepy or exhausted while driving during the day or at night due to sleep deprivation from long-haul truck driving.
	Inexperienced truck driver	Inexperienced	Driving by a driver with little experience or no training on how to drive safely or on driving-related regulations and laws.
Safety standard of STTs	Defected vehicle body	Body	The vehicle configuration (wheels, tires, engine, axles, and wheel bearings) is defective.
	Unlocked twistlocks	Twistlocks	The twistlock device preventing the moving or falling of a container from the trailer is not locked into the corners of the container.
	Defected coupling and driving support devices	Coupling	The coupling devices used to couple a semitrailer to the rear of a tractor are deformed, damaged, and cracked because the thickness of metal at any point is reduced to less than its original thickness and there is a trailer attached, while the broken driving support devices include lights, turn signals, tail lights, and side-view mirrors that cannot be used during driving.
	Truck overloading	Overloading	Vehicle is overloaded with goods which violates weight limitation regulations that do not allow the total loaded weight of STT to be greater than 21,727 kgs for a 20 foot standard container or no more than 26,780 kgs for a 40 foot container.

Effects of STT Transportation and Research Hypothesis

Many studies found that freight transportation by trucks had effects on on-road people and near-road populations in three major ways. Firstly, truck transportation potentially caused severe injuries and fatalities in crashes because of the neglect of drivers and the truck defect (Elvik et al., 2004; Duke et al., 2010; Copsey et al., 2010; Ratanavaraha & Suangka, 2014; Kamla, Parry, & Dawson, 2019). Secondly, traffic congestion occurred when the freight traffic reached maximum road capacity and the road users could suffer from traffic congestion in different ways, such as chronic stress (Zhang and Batterman, 2013), travel delay (Fei et al., 2016; Wu et al., 2017), and fatigue (Leechawengwongs et al., 2006). Finally, people were suffering from toxic gas emissions from freight vehicles idling on crowded roadways. Driver exposure to toxic gas could adversely affect the lungs and heart and aggravate heart disease and some types of cancer (Shaheen & Lipman, 2007; European Environment Agency, 2011; Laxe et al., 2016; Rajé et al., 2018).

Based on the above literature, this research postulated that the relationships among variables in an original SEM model were illustrated in Figure 2. In the model, ten endogenous variables were classified into two latent factors: 1) dangerous behaviors of STT drivers (Driver), and 2) safety standard of STTs (Truck). These two latent factors were assumed to be interrelated and have a direct effect on three endogenous variables (i.e.

traffic congestion (Congestion), air pollution emission (Pollution), and road accidents (Accident)), which had no interaction with each other. Apart from these variables, there were 13 exogenous variables (i.e. e1-e10 and d1-d3) which were the residuals of each endogenous variable, and all of their coefficients were determined as one theoretically required by SEM technique.

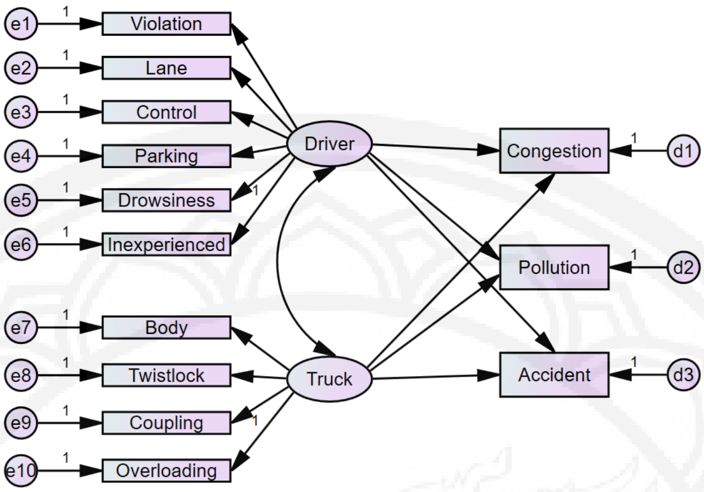

Figure 2 An original SEM model

Based on the research objectives, there were three major hypothesis in an original SEM model as follow.

Hypothesis 1: **H_0:** The latent variable "Driver" <u>has no direct effect</u> on traffic congestion, air pollution emission, and road accidents.

H_1: The latent variable "Driver" <u>has a direct effect</u> on traffic congestion, air pollution emission, and road accidents.

Hypothesis 2: **H_0:** The latent variable "Truck" <u>has no direct effect</u> on traffic congestion, air pollution emission, and road accidents.

H_1: The latent variable "Truck" <u>has a direct effect</u> on traffic congestion, air pollution emission, and road accidents.

Hypothesis 3: **H_0:** The latent variable "Driver" <u>is not interrelated</u> to the latent variable "Truck".

H_1: The latent variable "Driver" <u>is interrelated</u> to the latent variable "Truck".

Study Sample and Sampling Technique

Mixed sampling methods were used. First, the communities in Laem Chabang municipality were purposively selected because most communities, including Ban Ao Udom, Ban Khao Numsub, Ban Sak Yai Chin, Wat Manorom, and Huai Lek, in this municipality are located in the transportation area of the largest seaport of Thailand and the number of deaths and injuries from road accidents has continuously increased. In addition, the dangers of STT transportation in these five communities have continued to rise due to the growing number of industries in Chonburi province and other EEC areas. Second, the respondents to the questionnaire were randomly selected based on convenience in the survey. The number of respondents included in the survey was calculated using the Taro Yamane formula with a 95% confidence level. With the population of 19,453 residents in the five communities, the sample size was 391.9 or approximately 392.

Development of Questionnaire and Survey

The questionnaire was organized into four main parts. The first part comprised the questions regarding the socio-economic of the respondents (gender, age, occupation, residential area, accident experience, and residence status). The second part contained a list of ten hazards regarding STT transportation in the five communities. The respondents were asked to rate each danger using a four-point scale (very dangerous = 4, dangerous = 3, almost dangerous = 2, and not dangerous = 1). The third part consisted of a statement asking the respondents to evaluate the incidence rate of traffic congestion, air pollution emission, and road accidents of the five communities using a four-point scale (very good = 4, good = 3, decadent = 2, and very decadent = 1). To ensure the validity of a questionnaire, five transport and logistics experts from the Port Authority of Thailand, and educational institutions, including two heads of communities, were asked to investigate the content validity of the questionnaire using the index of item-objective congruence (IOC). The valid questions obtaining an IOC score between 0.67 and 1.00 were maintained, while questions with an IOC score lower than 0.5 were excluded from the questionnaire. After that ten respondents, based on the minimum number suggested by Isaac & Michael (1995), were invited to join the pilot study aiming to investigate the ease of questionnaire format and understanding the words adopted. The minor change was made based on the recommendation of experts and respondents. After that a questionnaire survey was randomly distributed to the respondents in the five communities.

Results and Discussion

Results from Questionnaire Survey

The sideway survey lasted four months from December 2018 to March 2019. The paper-based questionnaires were randomly distributed to 490 residents in their houses, at office buildings, along streets in the communities, at local markets, and at roadside shops. This survey was conducted in both peak and off-peak hours, mostly during the daytime on weekdays and weekends. The researcher avoided response bias by thoroughly explaining the research objectives, the importance of the survey, and the expected benefits for communities. Each questionnaire was collected immediately after the respondent had finished the form. Finally, 76 questionnaires (15.5%) were excluded due to incompleteness of answers, while 414 completed questionnaires (84.5%), which was greater than the required sample size of 392, were used for the analysis. Cronbach's Alpha was used to test the reliability of the questionnaire using SPSS 23. The value of Cronbach's Alpha was 0.75 indicating that the data collected were reliable. Table 2 describes the socio-economic characteristics, accident experience, and residence status of the respondents, while the data of each attribution was summarized in Table 3.

Table 2 Socio-economic characteristics of respondents

Information		Frequency	Percentage
Gender	Male	157	37.9
	Female	257	62.1
	Total	**414**	**100**
Community	Ban Ao Udom	65	15.7
	Ban Khao Numsub	61	14.7
	Ban Sak Yai Chin	113	27.3
	Wat Manorom	90	21.7
	Huai Lek	85	20.5
	Total	**414**	**100**

Table 2 (Cont.)

Information		Frequency	Percentage
Age (years)	< 21	142	34.3
	21-30	139	33.4
	31-40	93	22.4
	> 40	40	9.6
	Total	**414**	**100**
Occupation	Student	201	48.6
	Teacher/Lecturer	32	7.7
	General employee	49	11.8
	Government officer	24	5.8
	Private officer	40	9.7
	Unemployed	20	4.8
	Trailer-truck driver	13	3.1
	Other	35	8.5
	Total	**414**	**100**
Accident experience	None	225	54.3
	One or more	189	45.7
	Total	**414**	**100**
Residential status	Temporary	306	73.9
	Permanent	108	26.1
	Total	**414**	**100**

Table 3 Summary of attribution data

Abbreviation	No.	Minimum	Maximum	Mean		Std. Deviation
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic
Violation	414	1	4	3.69	.034	.693
Lane	414	1	4	3.76	.028	.567
Control	414	1	4	2.77	.046	.931
Parking	414	1	4	3.59	.035	.703
Drowsiness	414	1	4	2.43	.068	1.374
Inexperienced	414	1	4	2.98	.044	.894
Body	414	1	4	2.53	.068	1.382
Twistlock	414	1	4	3.47	.028	.572
Coupling	414	1	4	3.39	.034	.696
Overloading	414	1	4	2.23	.067	1.373
Crash	414	1	4	3.40	.029	.597
Pollution	414	1	4	3.22	.030	.620
Congestion	414	1	4	3.28	.028	.567

Principal Component Analysis with Varimax Method

After reliability of data was tested, the author conducted factor analysis using principal component analysis via SPSS 23 in order to investigate the consistency between the survey data and the theoretical reference. Ten variables, as described in Table 1, were analyzed by fixing two factors with varimax method, and KMO statistics was used to test the effectiveness of factor analysis. The results shown that KMO= 0.689 (p-value=0.00). The total contribution of the two factors was 50.346%, where factor 1 explains 29.991%, and factor 2 explains 20.355%. The results of the varimax rotated factor analysis and the factor loads of each item were presented in Table 4. The results demonstrated that the variables were grouped into two factors which were in line with the theory of Elvik et al. (2004), Leechawengwongs et al. (2006), Shaheen & Lipman (2007), Duke et al. (2010), Copsey et al. (2010), European Environment Agency (2011), Zhang & Batterman (2013), Ratanavaraha & Suangka, (2014), Fei et al. (2016), Laxe et al. (2016), Wu et al. (2017), Rajé et al. (2018), and Kamla, Parry, & Dawson (2019). Therefore, both factors were designated as the latent variables in a SEM model.

Table 4 Factor loads of items

Variable	Factor 1	Factor 2
Violation	0.862	-0.075
Lane	0.858	-0.054
Control	0.623	-0.027
Parking	0.804	-0.149
Drowsiness	0.699	-0.131
Inexperienced	0.549	0.322
Body	-0.010	0.700
Twistlock	0.073	0.669
Coupling	0.161	0.551
Overloading	0.013	0.552

Structural Equation Modeling and Hypothesis Test

Before SEM was performed in AMOS 21, multicollinearity among ten endogenous variables was tested by using variance inflation factor, and the results shown that all coefficients of variance inflation factor between paired variables were less than 3 indicating no multicollinearity. However, normality assumption was violated as the distribution of data was skew (|c.r.|>1.96) and the kurtosis was leptokurtic (|c.r.|>1.96). To relax the normality assumption; thus, the asymptotically distribution-free method was used in SEM technique instead of maximum likelihood method.

The goodness of fit in Table 5 indicated that the original SEM model was not fit with the data; therefore, the new model, as illustrated in Figure 3, was adjusted based on the modification indices. The adjustment was iteratively conducted until the modification indices could not improve the goodness of fit of the model. Table 5 shown that the adjust SEM model was fit with the data as CMIN/DF was less than 2 (p-value=0.103), while the values of GFI, AGFI, NFI, IFI, TLI were greater than 0.9. RMR was close to 1 and RMSEA was less than 0.05 (p-value=0.85), whereas the HOELTER (0.05) was greater than 200 indicating the sample was sufficient. Based on the statistics of regression weights in Table 6 and the standardized effects of variables in Table 7, for the first hypothesis, there was sufficient evidence to conclude that the latent variable "Driver" has a direct effect on only road accidents, but has an indirect effect on traffic congestion and air pollution emission. For the second hypothesis, there was sufficient evidence to summarize that the latent variable "Truck" has a direct effect on all variables, but has an indirect effect on traffic congestion and air pollution emission only. For the third hypothesis, the correlation coefficient of 0.594 between the latent variable "Driver" and the latent variable "Truck", as shown in Table 8, indicates that they are moderately correlated.

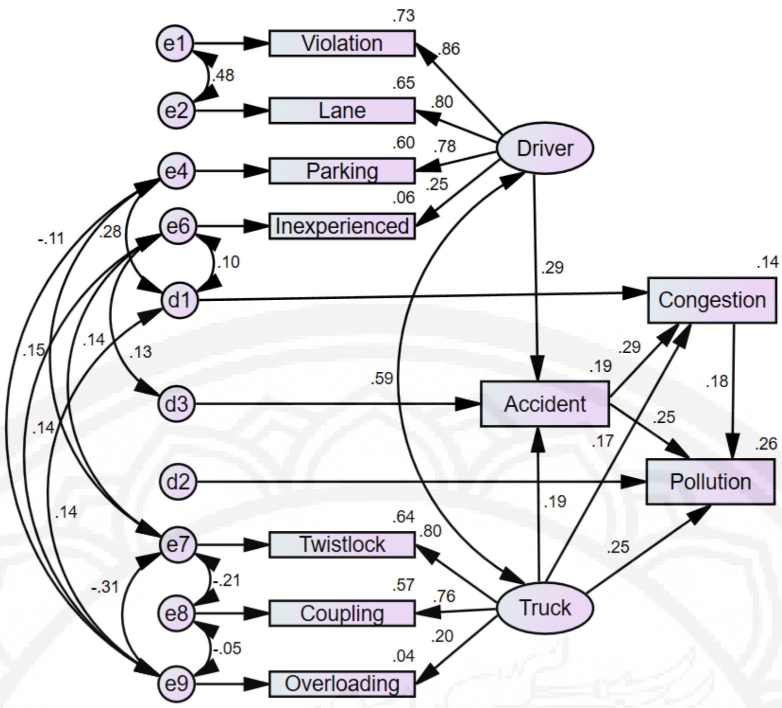

Figure 3 Adjusted SEM model with standardized effects

Table 5 The goodness of fit of models

Statistics test	Original model	Adjusted model
Chi-square	522.061 (p-value = 0.000)	25.866 (p-value = 0.103)
Degrees of freedom	61	18
CMIN/DF	8.558	1.437
RMR	0.137	0.027
GFI	0.829	0.996
AGFI	0.745	0.987
NFI	0.683	0.914
IFI	0.709	0.972
TLI	0.624	0.923
RMSEA	0.135 (p-value = 0.000)	0.033 (p-value = 0.85)
HOELTER (0.05)	64	461

Table 6 Regression weights

SEM variable			Estimate	S.E.	C.R.	P
Accident	<---	Truck	0.404	0.245	1.647	*
Accident	<---	Driver	0.751	0.228	3.291	**
Congestion	<---	Accident	0.278	0.051	5.468	***
Congestion	<---	Truck	0.344	0.191	1.802	*
Inexperienced	<---	Driver	1			
Parking	<---	Driver	2.282	0.374	6.102	***
Lane	<---	Driver	1.982	0.316	6.269	***
Violation	<---	Driver	2.443	0.422	5.789	***
Overloading	<---	Truck	1			
Coupling	<---	Truck	1.904	0.553	3.445	***

Table 6 (Cont.)

SEM variable			Estimate	S.E.	C.R.	P
Twistlock	<---	Truck	1.694	0.539	3.144	**
Pollution	<---	Accident	0.255	0.057	4.485	***
Pollution	<---	Truck	0.552	0.217	2.545	**
Pollution	<---	Congestion	0.197	0.052	3.769	***

Remark: ***, **, * Indicates significance at 1%, 5% and 10% respectively

Table 7 Standardized effects of variables

Dependent Variable	Standardized Effects	Independent Variable			
		Truck	Driver	Accident	Congestion
Accident	Direct effects	0.189	0.292	0	0
	Indirect effects	0	0	0	0
	Total effects	**0.189**	**0.292**	**0**	**0**
Congestion	Direct effects	0.166	0	0.287	0
	Indirect effects	0.054	0.084	0	0
	Total effects	**0.220**	**0.084**	**0.287**	**0**
Pollution	Direct effects	0.251	0	0.247	0.185
	Indirect effects	0.087	0.088	0.053	0
	Total effects	**0.338**	**0.088**	**0.3**	**0.185**
Twistlock	Direct effects	0.801	0	0	0
	Indirect effects	0	0	0	0
	Total effects	**0.801**	**0**	**0**	**0**
Coupling	Direct effects	0.756	0	0	0
	Indirect effects	0	0	0	0
	Total effects	**0.756**	**0**	**0**	**0**
Overloading	Direct effects	0.2	0	0	0
	Indirect effects	0	0	0	0
	Total effects	**0.2**	**0**	**0**	**0**
Violation	Direct effects	0	0.857	0	0
	Indirect effects	0	0	0	0
	Total effects	**0**	**0.857**	**0**	**0**
Lane	Direct effects	0	0.805	0	0
	Indirect effects	0	0	0	0
	Total effects	**0**	**0.805**	**0**	**0**
Parking	Direct effects	0	0.777	0	0
	Indirect effects	0	0	0	0
	Total effects	**0**	**0.777**	**0**	**0**
Inexperienced	Direct effects	0	0.254	0	0
	Indirect effects	0	0	0	0
	Total effects	**0**	**0.254**	**0**	**0**

Table 8 Correlations

Pairs of variables			Estimate
Driver	<-->	Truck	0.594
e6	<-->	e9	0.144
e9	<-->	e7	-0.312
e4	<-->	e9	-0.108
e4	<-->	e7	0.146
e4	<-->	d1	0.284
e9	<-->	d1	0.14
e6	<-->	e7	0.139
e6	<-->	d3	0.126
e6	<-->	d1	0.099
e8	<-->	e7	-0.207
e9	<-->	e8	-0.046
e2	<-->	e1	0.479

Research findings and Implications

In general, the findings were in line with the existing literature used as the reference for conceptualizing the framework in SEM model. The results illustrated that air pollution emission was affected by all four variables. Among these, the safety standard of STTs caused the greatest total impact on the emission of air pollutants, followed by road accidents, traffic congestion, and behaviors of STT drivers respectively. Traffic congestion was the second most sensitive variable in the model as it was impacted by three variables (i.e. road accidents influenced it the most, followed by the safety standard of STTs and the behaviors of STT drivers respectively). Compared with others, road accidents were the least sensitive variable in the model as it was affected by only the behaviors of STT drivers and the safety standard of STTs. The moderate association between two latent factors in the model indicated that the failure of safety standard of STTs would cause the STT drivers to drive dangerously. The model also shown that traffic congestion and road accidents were the mediator variables passing the impacts from the safety standard of STTs and the behaviors of STT drivers to air pollution emission.

Factor analysis shown that air pollution emission in five communities was considerably affected if the safety standard of STT was not maintained, especially the twistlock device (factor loading=0.80) which was the most critical influencing STTs' safety. The air pollutant was likely to rise if the twistlocks were unlocked with the trailer. This pointed out a new agenda for the policy makers and legal enforcement officers to strictly control this device if the prevention of environmental and safety problems were a target. To the author's observation, many road accidents took place due to the unlock twistlocks causing the container dropping from the trailer, which potentially slowed down traffic and sometimes blocked other vehicles trying to pass the accident, resulting in traffic congestion which emitted considerable air pollutants. This argument corresponded to the finding of Pasidis (2017) who found that accident could cause severe traffic congestion. This finding was also in line with the traffic-accident report of Royal Thai Police (2015) which stated that falling down of container, towing failure or the trailer uncoupling while towing were potential causes of accidents in LCM due to defects of the coupling device and the neglect of the truck drivers to firmly install the coupling devices (pin, jaw, hook, or ball) or twistlocks to the rear of a tractor-trailer.

An interesting finding reflecting the existing problem in LCM was that STT overloading could cause traffic congestion and accident. The logic that could explain this relationship can be drown from the studies of Tanaka (2016) and Pasidis (2017). Tanaka (2016) highlighted the effects of truck overloading on the traction, collision, and breaking forces which reduced braking efficiency and the maneuverability of trucks so that the containers could easily fall off the trailer resulting in a roll-over, which substantially damaged the pavement structure causing pot holes and alligator crack in the pavement surface, slippage of the surface layer of the road, and destruction of pavement. Sequentially, the damaged road surface could cause road accidents and traffic congestion (Pasidis, 2017).

It was surprised to know that traffic congestion had no impact on road accidents, but it was the cause of air quality degradation. This finding was in line with the work of Zhang and Batterman (2013) who explored that during traffic congestion the drivers accelerated and used brake repeatedly during traffic jam, the STTs burn more fuel generating CO, CO_2, NO_X, SO_2, and particulate matter (European Environment Agency, 2011). Another surprising finding was that the STT drivers' behaviors had the lowest effects on air pollution compared with others. However, it was worth to control this factor because the dangerous behaviors of STT drivers, especially the violation of speed limit (loading factor=0.86), could lead to road accidents. In addition, the correlation of 0.59 implied that the STT drivers' dangerous behaviors interrelated to the safety standard of STTs increasing the possibility of road accidents, traffic congestion and air pollution emission. Hence, reducing dangerous behaviors would not only decrease air pollution emission from STT transportation, but also diminish the rate of deaths and injuries in crashes.

According to the above theoretical findings, the implementation of preventive measures towards the safety standard of STTs and behaviors of STT drivers could not only prevent communities from road accidents and traffic congestion, but also reduce air pollution emission. The current study suggested two major ways possibly addressing air pollution from STT transportation. First, the enforcement of laws (e.g. Road Traffic Act. B.E. 2522 (1979)) should be strictly implemented on the STT companies and drivers. Increasing the number of police-checking units might drive legal enforcement power and other measures. Alternatively, the transport managers should thoroughly plan a trip and inspect the vehicles, including the driving support devices, twistlocks and coupling devices, to avoid a STT breakdown which could cause an accident as well as air pollution. Second, the traffic-control measures successfully implementing in other parts of Thailand should be adopted to control the dangerous behaviors of STT drivers. For example, an adoption of engineering method (e.g. rumble strips) that shown high potential to address the safety issue in the highways (Leechawengwongs et al., 2006), while providing training courses to improve the driving knowledge and skills required under the legislation could reduce the rate of road accidents which was the major cause of traffic congestion and air pollution.

Conclusions

The current study explored that air pollution from STT transportation was influenced by all variables analyzed in the SEM model. Among these, the safety standard of STTs played the most considerable role on air pollution emission, followed by the road accidents, and traffic congestion, which were the mediator variables influenced by the safety standard of STTs and the dangerous behaviors of STT drivers. It was encouraged to address the air pollution by controlling STTs' safety standard and the STT drivers' dangerous behaviors which were the original sources of air pollutants. Alternatively, if the original sources could not be eliminated, it was urged to launch the effective measures to prevent traffic congestion and road accidents which were the intermediate sources of air pollution. The effective way was to control the STTs' safety standard by enforcing laws and providing training courses for STT drivers. Another way was to control the dangerous behaviors of STT drivers by using other successful strategies, such as rumble strips, radar speed gun, and speed warning or speed limit signs, or implementing policies (e.g. a congestion charging policy to reduce travelling activities, and an access restriction measure to control the number of vehicles in communities). The general role and responsibility of the relevant policy makers and law enforcement officers should be further analyzed for increased managerial and theoretical knowledge. The future studies in both transport and environment fields might generate a study framework by using this study as a reference for analysis of other managerial concepts, while the author also plans to continue studying the above topics which will not only contribute to the literature in transportation and environment, but also will help policy makers, including governmental authorities and truck operators, to capture ways they can sustain the communities.

Acknowledgements

The author thanks all the experts who reviewed and evaluated the attributes of the dangers from STT drivers, and the safety standard of STTs. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. There's no financial and personal interest influencing the validity of research.

References

Asgari, N., Hassani, A., Jones, D., & Nguye, H. H. (2015). Sustainability Ranking of the UK Major Ports: Methodology and Case Study. *Transportation Research Part E: Logistics and Transportation Review, 78*, 19-39. https://doi.org/10.1016/j.tre.2015.01.014

Chonburi Provincial Public Health Office. (2019). *Top-Ten Disease Causes of Outpatient in Chonburi Province. Chonburi, Thailand.* Retrieved from http://hdc2.cbo.moph.go.th/hdc/main/index_pk.php

Copsey, S., Christie, N., Drupsteen, L., van Kampen, J., Kuijt-Evers, L., Schmitz-Felten, E., & Verjans, M. (2010). A Review of Accidents and Injuries to Road Transport Drivers. Luxembourg: Publications Office of the European Union.

Dastoorpoor, M., Idani, E., Khanjani, N., Goudarzi, G., & Bahrampour, A. (2016). Relationship between Air Pollution, Weather, Traffic, and Traffic-Related Mortality. *Trauma Monthly: Journal of Trauma and Emergency Medicine, 21*(4), e37585. DOI: 10.5812/traumamon.37585

Davies, P. (2006). *Off-Dock Storage of Empty Containers in the Lower Mainland of British Columbia: Industry Impacts and Institutional Issues.* Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.410.2639&rep=rep1&type=pdf

Department of Land Transport. (2015). *Truck Tractor and Trailer and Semitrailer Registration in Thailand.* Thailand: Department of Land Transport.

Duke, J., Guest, M., & Boggess, M. (2010). Age-Related Safety in Professional Heavy Vehicle Drivers: A Literature Review. *Accident Analysis & Prevention, 42*(2), 364-371. https://doi.org/10.1016/j.aap.2009.09.026

Elvik, R., Christensen, P., & Amundsen, A. (2004). *Speed and Road Accidents: An Evaluation of the Power Model. Oslo: Institute of Transport Economics (TOI).* Retrieved from https://lib.ugent.be/fulltxt/RUG01/001/813/795/RUG01-001813795_2012_0001_AC.pdf

European Environment Agency. (2011). *Do Lower Speed Limits on Motorways Reduce Fuel Consumption and Pollutant Emissions?.* Retrieved from https://www.eea.europa.eu/themes/transport/speed-limits

Fei, L., Zhu, H. B., & Han, X. L. (2016). Analysis of Traffic Congestion Induced by the Work Zone. *Physica A: Statistical Mechanics and its Applications, 450*, 497-505. https://doi.org/10.1016/j.physa.2016.01.036

IBI Group. (2006, December 12). *Inland Container Terminal Analysis: Final Report.* Retrieved from http://www.th.gov.bc.ca/pacificgateway/documents/061215_inland_container_terminal_analysis.pdf

Industrial Estate Authority of Thailand. (2015). *Industrial Estates in Thailand.* Retrieved from https://www.ieat.go.th/en/investment/about-industrial-estates/industrial-estates-in-thailand

Isaac, S., & Michael, W. B. (1995). *Handbook in research and evaluation.* San Diego, CA: Educational and Industrial Testing Services.

Jongmeewasin, S. (2016). Lesson Learned: Ban Ao Udom Community, Tungsukla, Sriracha, Chonburi. Chonburi: The Assembly of NGOs.

Kamla, J., Parry, T., & Dawson, A. (2019). Analysing Truck Harsh Braking Incidents to Study Roundabout Accident Risk. *Accident Analysis and Prevention, 122*, 365-377. https://doi.org/10.1016/j.aap.2018.04.031

Laemchabang City Municipality. (2012). *Strategic Plan for Laem Chabang Municipality Development.* Retrieved from http://www.lcb.go.th/_files/data/2012_10_05_090755_i7abyrt2.pdf

Lan, T. T., Kanitpong, K., Tomiyama, K., Kawamura, A., & Nakatsuji, T. (2019). *Effectiveness of Retro-Reflective Tape at the Rear of Heavy Trucks to Increase Visibility and Reduce Rear-End Collisions.* Retrieved from https://trid.trb.org/view/1581167

Laxe, F. G., Bermúdez, F. M., Palmero, F. M., & Novo-Corti, I. (2016). Sustainability and the Spanish Port System. Analysis of the Relationship between Economic and Environmental Indicators. *Marine Pollution Bulletin, 113*(1-2), 232-239. https://doi.org/10.1016/j.marpolbul.2016.09.022

Leechawengwongs, M., Leechawengwongs, E., Sukying, C., & Udomsubpayakul, U. (2006). Role of Drowsy Driving in Traffic Accidents: A Questionnaire Survey of Thai Commercial Bus/Truck Drivers. *Journal of the Medical Association of Thailand, 89*(11), 1845-1850.

Maguire, A., Ivey, S., Golias, M. M., & Lipinski, M. E. (2010). Relieving Congestion at Intermodal Marine Container Terminals: Review of Tactical/ Operational Strategies. *In 51st Annual Transportation Research Forum, Arlington, Virginia, 11-13 March 2010* (pp. 1-15). Paris, TX: Transportation Research Forum.

Motono, I., Kimito, H., Furuichi, M., & Suzuki, S. (2014). A New Concept of Off-Dock Container Traffic Control for Heavily Congested Ports. *In The Fifth International Conference on Transportation and Logistics (T-LOG).* Bangkok: Chulalongkorn University.

Pasidis, I. (2019). Congestion by Accident? A Two-Way Relationship for Highways in England. *Journal of Transport Geography, 76,* 301-314. https://doi.org/10.1016/j.jtrangeo.2017.10.006

Rajé , F., Tight, M., & Pope, F. D. (2018). Traffic Pollution: A Search for Solutions for a City Like Nairobi. *Cities, 82,* 100-107. https://doi.org/10.1016/j.cities.2018.05.008

Ratanavaraha, V., & Suangka, S. (2014). Impacts of Accident Severity Factors and Loss Values of Crashes on Expressways in Thailand. *IATSS Research, 37*(2), 130-136. https://doi.org/10.1016/j.iatssr. 2013.07.001

Royal Thai Police. (2015). *The Situation of Reported Traffic Accidents by Type of Vehicles, Damages and Alleged Offenders, Central Region: 2013-2015.* Bangkok: National Statistical Office.

Rys, D., Judycki, J., & Jaskula, P. (2017). Impact of Overloaded Vehicles on Road Equivalency Factors and Service Period of Flexible Pavement. In A. Loizos, I. L. Al-Qadi, & T. Scarpas (Eds.), *Bearing Capacity of Roads, Railways and Airfields* (pp. 459-465). Boca Raton, Florida: CRC Press.

Senarak, C. (2016). The Use of Seasons in Preventing Marine Pollution from Cargo Ships in Laem Chabang Port, Thailand. *Environment and Natural Resources Journal, 2016, 14*(1), 8-16. Retrieved from https://www.tci-thaijo.org/index.php/ennrj/article/view/67230

Shaheen, S. A., & Lipman, T. E. (2007). Reducing Greenhouse Emissions and Fuel Consumption-Sustainable Approaches for Surface Transportation. *IATSS Research, 31*(1), 6-20. https://doi.org/10.1016/S0386-1112(14)60179-5

Tanaka, Y. (2016). Overloading and Road Management. Retrieved from https://www.arrivealive.mobi/overloading-and-road-safety

Thailand Board of Investment. (2016). *Thailand's Eastern Economic Corridor (EEC): The Special Economic Zone (SEZ) for the Future of ASEAN.* Thailand: Thailand Board of Investment.

United Nations Conference on Trade and Development. (2018). Review of Maritime Transport 2018. New York: United Nations. Retrieved from https://unctad.org/en/PublicationsLibrary/rmt2018_en.pdf

Wen, H., Xuhong, L., & Jie, H. (2007). *Issue of Highway Truck Overloading and Its Social Impacts in China: Exemplified by Anhui Province.* Nanjing: Southeast University.

World Health Organization. (2015). Global Status Report on Road Safety 2015. Geneva: Management of Noncommunicable Diseases, Disability, Violence and Injury Prevention (NVI).

World Health Organization. (2019). *How Air Pollution is Destroying our Health.* Retrieved from https://www.who.int/air-pollution/news-and-events/how-air-pollution-is-destroying-our-health

Wu, K., Chen, Y., Ma, J., Bai, S., & Tang, X. (2017). Traffic and Emissions Impact of Congestion Charging in the Central Beijing Urban Area: A simulation Analysis. *Transportation Research Part D, 51,* 203-215.

Yap, W. Y. (2013). 80 Million-Twenty-Foot-Equivalent-Unit Container Port? Sustainability Issues in Port and Coastal Development. *Ocean & Coastal Management, 71,* 13-25.

Zain, R. M., Rahman, M. N., Saibani, N., Nopiah, Z. M., Ramli, A., & Jusoh, N. (2015). Exploring the Delays at Empty Container Off-Dock Depots: Useful Perceptions by Stakeholders. *Management, 5*(5), 148-159.

Zhang, K., & Batterman, S. (2013). Air Pollution and Health Risks Due to Vehicle Traffic. *Science of the Total Environment, 450,* 307-316.