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Identification of Factors Affecting Road Traffic Injuries Incidence and Severity in Southern Thailand Based on Accident Investigation Reports

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Abstract: Thailand has the second-highest rates of road traffic mortality globally. Detailed information on the combination of human, vehicle, and environmental risks giving rise to each incident is important for addressing risk factors holistically. This paper presents the result of forensic road traffic investigation reports in Thailand and determines risk factor patterns for road traffic injuries. Detailed forensic reports were extracted for 25 serious traffic accident events. The Haddon matrix was used to analyze risk factors in three phases stratified by four agents. The 25 events analyzed involved 407 victims and 47 vehicles. A total of 65.8% of victims were injured, including 14.5% who died. The majority (66.1%) of deaths occurred at the scene. Human-error-related factors included speeding and drowsiness. Passenger risks included not using the seat belt, sitting in the cargo area and the cab of pickups. Overloaded vehicles, unsafe car modifications, no occupant safety equipment and having unfixed seats were vehicular risks. Environmental risks included fixed objects on the roadside, no traffic lights, no guard rails, no traffic signs, and road accident black spots. At present, traffic accidents cause much avoidable severe injury and death. The outcome of this paper identifies a number of preventable risk factors for traffic injury, and importantly examines them in conjunction. Road traffic safety measures need to consider how human, vehicle, and environmental risks intersect to influence injury likelihood and severity. The Haddon matrix is useful in identifying these pre- and post-accident risk factors. Furthermore, the sustainable preventions of road traffic injury need to address these risks together with active law enforcement.

Keywords: road traffic injury; risk factor; road traffic investigation; Haddon matrix

1. Introduction

Road traffic injury is a significant cause of morbidity and mortality and is in the top 10 causes of death globally, leading to approximately 1.3 million deaths each year. Among populations aged 15–29 years, road traffic injuries are the top cause of death [1]. Almost 75% of road traffic accident deaths affect males aged under 25 years [2]. As well as mortality, road traffic injuries lead to significant morbidity, with global estimates of more than 20 million non-fatal road traffic injuries occurring each year. The disability and economic impacts of fatal and non-fatal injuries are substantial. As well as the age distribution of road traffic injury, socioeconomic status also plays a role in injury risk. Low- and middle-income countries experience more than 90% of road traffic accident mortality [2].

Southeast Asia is a particular hot spot for road traffic injury, accounting for 25% of global mortality, or more than 300,000 deaths annually. Within this region, Thailand has the highest rate of mortality from road traffic injury, and in 2015 had the second highest rate globally, following Libya, with an estimated fatality rate of around 36.2 per 100,000 population [3]. The incidence of traffic injuries in Thailand rose from 449.0 per 100,000 in 2012 to 524.9 cases per 100,000 in 2016 [4]. An average of 20,973 deaths were recorded each year between 2011 and 2019 in the country [5].

As in many other countries, Thai road traffic injury and road traffic mortality are connected to a number of identified and preventable risk factors. Firstly, motorcycles are associated with nearly 40% of all road traffic accidents [2,5]. Male sex and being aged 15–24 years also increase the risk of road traffic injury [6]. Furthermore, recent surveys have shown that around two-thirds of car users regularly wear safety belts [7], and more than half of motorcycle users did not regularly wear helmets [8].

National statistics such as those reported here, however, only give an overall view of the road traffic safety situation. Each road traffic incident has its own set of, generally preventable, drivers impacts in terms of fatalities and injuries and primary causes such as excess speed, overloading, and types of vehicles [9]. Moreover, climate change and extreme weather are leading to changing risks for severe road traffic accidents and injuries [10], as well as spatial, temporal, and community aspects [11]. Finally, the number of cars per day, crosswalks, road types, highway speed limits, and the real-time post-impact traffic accident management system should be taken into account [12,13]. Examining individual accident events in detail can help us understand where preventative measures could have been employed. The Haddon Matrix is a tool which can help to examine road traffic accidents in detail using a qualitative analysis method [14–16]. It allows the combined assessment of conditions leading to the severity of accidents and injuries, in terms of human, vehicular, physical environment, and socio-economic environment factors. This analytical method then adds a temporal dimension examining how these three factors operated pre-crash, during the crash, and post-crash.

The purpose of this paper is to use the Haddon Matrix approach to examine in detail a number of fatal and non-fatal injury incidents in Thailand and consider the appropriate injury prevention techniques. This information can be used to support the Thai government in implementing policies to reduce the number of road traffic injuries in Thailand. The objectives of this study were: 1. to determine the factors influencing injury and injury severity using Haddon's matrix model and 2. to understand drivers of road traffic injuries in Thailand by using in-depth road traffic investigations. The framework of this paper has flowed as follows: Section 2 provides an overview of factors potentially related to road traffic accidents and road traffic injuries. Section 3 details the data used. Section 4 describes the results in detail. Finally, Section 5 summarizes the important findings in this study.

2. Literature Reviews

2.1. Human Error Related to Road Traffic Accidents and Road Traffic Injuries

Various studies have found that the main causes of road traffic accidents are linked to human error such as speeding, distractions, alcohol-related errors, violation of traffic rules, and fatigue and drowsiness [17–20]. Human errors resulting in road accidents can be caused by drivers, passengers, and vulnerable road users such as pedestrians, cyclists, and motorcyclists [2,15]. Driver errors are common with the most important being excessive speeding [17,19,20], exhaustion from driving long distances [19,21,22], emotional driving [19], drinking alcohol [17,19], and inexperienced driving [15]. Passengers can also increase road traffic accident risk, particularly by distracting drivers [19]. Traffic accidents caused by pedestrian error, such as cutting closely in front of cars, walking on the road, and crossing the road away from crosswalks and roadways around facilities [11]. For example, to solve such problems, sub-Saharan Africa has reduced injuries around primary schools by providing demarcated places for children to cross roads, including crosswalks barriers to separate the walkway from vehicles, and improving the pedestrian area [1]. In addition, once an accident has occurred, other factors can also increase the risk of serious injury from the event. For example, age and gender affect the risk of serious injury, along with not using safety devices [19] and sitting in the cab and the cargo area. Previous studies found that falls from pickup truck cargo areas were associated with severe injuries in children [23–26]. Children in the cab and the cargo pickup trucks were at greater risk of injury than children in other vehicles [27]. Pre-hospital care post-impact at the scene was essential for survival and reducing disabilities among victims [28]. A lack of pre-hospital emergency care and the delays in transfers at the scene were associated with increased road traffic deaths [29].

2.2. Vehicle Risks Related to Road Traffic Accidents and Road Traffic Injuries

Vehicle safety standards in all vehicles are essential to the safety of drivers and passengers [17–20,28]. Several studies have found that vehicle qualities affecting accident risk include inadequate maintenance, mismatched tires [20,30,31], compromised braking [20], insufficient lighting, overloading, and the misuse or modification of vehicles for public transportation or as school vehicles [27,32,33]. A lack of safety equipment inside the vehicles contributes to a high risk of serious disability, serious injury, and death [23,26,27]. Transporting passengers in the cab and the cargo areas of pickup trucks are very dangerous, as the occupants are unsafe and can be ejected from the cargo or become stuck in the cab [18,26]. The accident severity can be clearly increased if the engine ignites or passengers are trapped inside the vehicle.

2.3. Environment Risks Related to Road Traffic Accidents and Road Traffic Injuries

Environmental risk assessments for road conditions should take into account both the physical enviroment (road design, weather conditions, fixed objects in safe zone) and the socioeconomic environment (community norms, policies, rules) [17–20,28]. In the literature, the impacts of environmental risks on road accidents were commonly fixed objects in the safety zone (trees, electric poles) [34,35]. Often, environment risk factors increased accident severity and severe injuries [18,33,35]. Vehicles hitting trees is a common roadside hazard in Thailand [18]. Roadside structures (signs, fences, barriers, trees, electrics) are the objects that impact road accidents the most [18,34]. The weather conditions have a negative effect on road traffic, increasing the severity of road traffic accidents and injuries [11]; the number of road accidents is impacted by the rainfall level in Thailand [36]. Furthermore, a community zone with the presence of facilities (street food vendors, supermarket) is influential on road traffic accidents and injuries [11].

3. Materials and Methods

3.1. Study Design

This study comprises a cross-sectional content analysis of road traffic investigation reports for traffic incidents occurring between November 2006 and April 2019 in the lower southern region of Thailand. Road traffic accident investigations in Thailand are assigned for investigation to teams at the district, the provincial, or the national level depending on their level of seriousness. For this analysis, we only considered cases assigned to the national-level teams. These comprised the most serious incidents with the inclusion criteria as follows: (1) road traffic injuries resulting in 5 or more deaths or 15 or more injuries; (2) road traffic incidents at sites that have had injuries and deaths occur previously, more than 2–5 times in the same month; (3) particularly noteworthy incidents from a community perspective, such as injuries to students or accidents involving public transportation or ambulances [37]; (4) these events were investigated using qualitative research methods by multidisciplinary teams from the Ministry of Public Health including epidemiologists, nurses, public health officers, civil engineers, police and other related agencies; and (5) the content of these reports was analyzed using Haddon's matrix to understand the key characteristics of each incident. These reports were compiled by the reginal Office of Disease Prevention and Control 12, Songkhla Province (ODPC12), Department of Disease Control (DDC), Ministry of Public Health (MOPH), Thailand. This is the responsible government body for documenting road traffic injuries in this part of Southern Thailand. The provinces covered by this investigation are ranked as having a high burden of traffic injury with more than 400 injury cases per 100,000 population, per year. We retrieved a total of 24 road traffic investigation reports and 407 victims, which met the inclusion criteria.

3.2. Data Extraction and Filtering Criteria

The data extraction was performed during April 2020. The first step of the study was to extract the full in-depth reports of selected road traffic injury incidents from the database of the reginal Office of Disease Prevention and Control 12, Songkhla Province, Thailand (ODPC12). We checked if the reports were prepared by multidisciplinary teams from the Ministry of Public Health including epidemiologists, nurses, public health officers, civil engineers, police, and other related agencies. We examined the study design and completeness of inspection outcomes from crash scenes, in-depth interviews with victims, eyewitnesses, and health staff, and information extracted from the medical records concerning ambulance and hospital treatment [38].

Recording forms were developed by the authors to extract the relevant variables from these reports for this study. Three experts who understand the concept of road traffic investigations and epidemiology verified the completeness of information captured in the recording forms. Variables extracted comprised the following:

1. Event characteristics: vehicle-related crash and/or other parties involved in incident (such as pedestrians), involvement of roadside object hazards, collision types, and type of vehicle;
2. Road user information: sex, age-groups, road user type (driver, passenger, pedestrian), characteristics of those injured (driver, passenger, pedestrian), number of victims, number of injured, and number of deaths;
3. Injury details: region of body injured consisted of head and neck, face, chest, abdomen and pelvis, extremities and pelvic girdle, and external and skin injuries [39];
4. Prehospital trauma care: type of assistance provided and mode of delivery to hospitals as reported by eyewitnesses, police officers, or rescue terms (First response unit: FR., Basic life support unit: BLS, Advanced life support unit: ALS);
5. Factors influencing the injury: this followed Haddon's matrix system addressing human, vehicle, physical environment, and socioeconomic environment factors which influenced likelihood of injury within three phases of influence (pre-event, event, post-event) [15,38,40].

In total, 24 road traffic investigation reports were chosen with a total of 25 events because two events were included in the same report. These reports covered events in five provinces in the lower southern region of Thailand namely, Trang, Satun, Phatthalung, Songkhla, and Pattani

3.3. Data Analysis

The data extraction was performed during April 2020. The first analysis step involved calculating descriptive statistics for the traffic incidents. Event characteristics, road user information, and injured body parts were described using frequencies and percentages.

Next, the extracted content from the traffic accident reports was evaluated qualitatively using Haddon's matrix model as an analytical framework. Factors influencing the likelihood and severity of injuries for each traffic accident were categorized in terms of the host, the vehicle, the physical environment, and the socioeconomic environment in three crucial temporal stages (the pre-event phase, the event phase, and the post-event phase) [16,38]. This analysis aims to identify determinants of road accidents themselves and also the determinants of injury, injury severity, and death at multiple levels and before, during, and after the accident. The advantages of this approach are the ability to identify structural and behavioral risk factors. The triangulation method was used to verify the completeness and the accuracy of data by the searcher team.

4. Results

4.1. Overview of Event Characteristics

Table 1 shows the details of the 25 road traffic investigation reports analyzed, involving 407 victims, 47 vehicles, and 27 roadside object hazards. Of the victims, 268 (65.8%) were injured, including 59 deaths (14.5%). Roadside objects were a factor in 18 events, of which 15 events related to tree hazards. Approximately 52.0% (n = 13) of events were single-vehicle accidents. The most common types of the single-vehicle accident were crashes with fixed objects such as a trees, electric poles, or concrete pillars, comprising 12 events (92.3%). The incidents with the highest number of injuries were a multiple-vehicle crash in front of a school with 34 injured, followed by an overturned bus crashing into a tree with 24 injured. The incidents with the highest number of deaths were a school pickup crashing into a tree with 10 casualties, followed by a worker pickup running off the road and crashing into trees with 7 persons deceased. Events in which all victims died consisted of a car burning after hitting a tree, a prime mover truck crashing into a pedestrian bridge, and a pickup crashing into a motorcycle.

Table 1. Traffic accident characteristics in terms of vehicle numbers, roadside object hazards, victims, injuries, and deaths classified by the number of vehicles involved in the incident.

Events	Roadside Objects	Victims	Total Injured (%)	Death (%) *
Single-vehicle crashes (13 events, 52.0% of 25 events)				
(Event 1) An excursion bus overturned	-	66	24 (36.4)	0 (0.0)
(Event 2) A car burning after hitting a tree	1 tree	4	4 (100.0)	4 (100.0)
(Event 3) A school pickup running off a road and crashing into a tree	1 tree	12	12 (100.0)	10 (83.3)
(Event 4) A car burning after hitting a tree	1 tree	3	3 (100.0)	2 (66.7)
(Event 5) A car hitting a tree	1 tree	2	2 (100.0)	1 (50.0)
(Event 6) A saloon car crashing into an electricity pole	1 utility pole	9	9 (100.0)	6 (66.7)
(Event 7) A pickup public transport pickup running off a road and crashing into a utility pole	1 utility pole	5	5 (100.0)	1 (20.0)
(Event 8) A prime mover truck crashing into a pedestrian bridge	1 concrete pillar	1	1 (100.0)	1 (100.0)
(Event 9) An overturned bus crashed into trees after hitting a pedestrian	2 trees	26	17 (64.5)	2 (7.7)
(Event 10) A chartered van crashing into trees and overturning	2 trees	15	12 (80.0)	6 (40.0)
(Event 11) An excursion pickup public transport running off a road and crashing into trees	2 trees	21	21 (100.0)	2 (9.5)
(Event 12) A pickup truck running off a road and crashing into a tree and a utility pole	1 tree and 1 utility pole	4	4 (100.0)	3 (75.0)
(Event 13) An armored pickup running off a road crashing into trees and overturning	3 trees	2	2 (100.0)	2 (100.0)
Two-vehicle crashes (7 events, 28.0% of 25 events)				
(Event 14) An ambulance crashing into a car, which then collided with pedestrians	-	13	10 (76.9)	1 (7.7)
(Event 15) A car u-turned crossed into the opposite lane and crashing a worker pickup truck, overturning and ran off the road	-	18	18 (100.0)	0 (0.0)
(Event 16) An ambulance crashing into the back of a prime mover truck	-	4	3 (75.0)	1 (25.0)
(Event 17) A school pickup crashing into a tree and overturning after a car crashed into the pickup	1 tree	20	18 (90.0)	1 (5.0)
(Event 18) A pickup crashing into a motorcycle	1 tree	2	1 (50.0)	1 (50.0)
(Event 19) A pickup truck crashing a public van, running off a road and hitting trees	2 trees	15	14 (93.3)	1 (6.7)
(Event 20) A truck crashing a worker pickup truck, running off a road and hitting two trees and a utility pole	2 trees and 1 utility pole	11	10 (90.9)	7 (63.6)

Table 1. *Cont.*

Events	Roadside Objects	Victims	Total Injured (%)	Death (%) *
Multi-vehicle crashes (5 events, 20.0% of 25 events)				
(Event 21) A pickup crashed into other pickups with the second pickup rolling and flipping over a passenger (3 vehicles)	-	18	18 (100.0)	2 (11.1)
(Event 22) A car crashing into an ambulance, which then crashed into a pickup (3 vehicles)	-	7	2 (28.6)	0 (0.0)
(Event 23) An excursion bus crashing into the back of another excursion bus, crashing into the back of a pickup (3 vehicles)	-	81	18 (22.2)	0 (0.0)
(Event 24) A car crashing into a pickup and running off the road, colliding with a prime mover truck (3 vehicles)	1 tree	8	6 (75.0)	5 (62.5)
(Event 25) A multiple-vehicle crash in front of a school zone (8 vehicles)	1 tree	40	34 (85.0)	0 (0.0)
Total	27	407	268 (65.8)	59 (14.5)

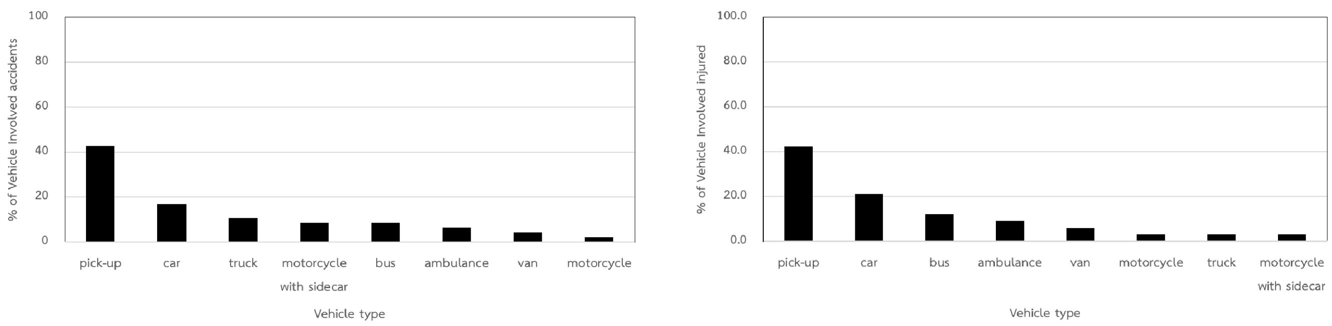
* Percentage of traffic incident victims who died.

The time of occurrence of road traffic injures in the 25 events are shown in Table 2. The most accidents occurred between midday and 3 p.m. The most injuries occurred in accidents between 3 p.m. and 6 p.m., with 36.9% of total injured and 27.1% of road traffic fatalities occurring then.

Table 2. Number of events, total injured, and death in road traffic injuries by time of day.

Time of Day	Number (25 Events)	%	Total Injured (n = 268)	%	Death (n = 59)	%
Midnight to 3.00 a.m.	0	0.0	0	0.0	0	0.0
3.01 a.m. to 6.00 a.m.	4	16.0	34	12.7	13	22.0
6.01 a.m. to 9.00 a.m.	3	12.0	31	11.6	10	16.9
9.01 a.m. to Midday	3	12.0	31	11.6	3	5.1
Midday to 3.00 p.m.	7	28.0	68	25.4	15	25.4
3.01 p.m. to 6.00 p.m.	6	24.0	99	36.9	16	27.1
6.01 p.m. t0 9.00 p.m.	0	0.0	0	0.0	0	0.0
9.01 p.m. to Midnight	2	8.0	5	1.9	2	3.4

Of the 47 vehicles in total, there were 17 (36.2%) vehicles whose occupants were injured. The maximum vehicle number involved in a single event was eight vehicles. Figure 1a shows that approximately 42.6% (n = 20) of vehicles involved in accidents were pickups, and 17.0% (n = 8) were cars. Figure 1b shows that the distribution of vehicle types was similar when we looked only at vehicles whose occupants were injured, approximately 42.4% (n = 14) of vehicle type involving injury were pickups, and 21.2% (n = 7) were cars.



(**a**) (**b**)

Figure 1. Frequency of vehicle type involved in accidents among: (**a**) the total 47 vehicles and (**b**) 33 vehicles where injury occurred.

4.2. Demographic Data of Road Users

Table 3 presents females as 1.6 times more likely to be injured than men. The median age of those injured was 27 years 5 months (range: 3 months–88 years). The case fatality rate was 22.0% (*n* = 59), and 1.2 times more women than men died. The median age of the deceased was 28 years (range: 3 months–82 years). The age distribution of injuries and deaths showed the highest number occurred among those aged less than 15 years, accounting for 63 (11.9%) injuries and accounting for 10 (16.9%) deaths. The highest case fatality rate (CFR) was in the age group of 40–44 years (38.1%). The vehicles associated with the most casualties were pickups, accounting for 133 (51.6%) injuries and 28 (49.1%) deaths. Most casualties were passengers, comprising 229 (85.5%) injuries and 46 (78.0%) deaths. This group was followed by drivers, comprising 29 (10.8%) injuries and 11 (18.6%) deaths. The highest case fatality rate (CFR) was found among drivers at 37.9%. One person could be injured in several body parts. The most frequently injured body regions were extremities and the pelvic girdle with 118 (44.0%) injuries, followed by the head/neck with 111 (41.4%) injuries. The most frequently injured body regions in fatal accidents were the head/neck in 45 (76.3%) accidents, followed by extremities and the pelvic girdle with 29 (49.1%). The highest case fatality rate (CFR) was in head/neck injuries (40.5%).

Table 3. Demographic details of road traffic injury victims by number and percentage.

Demographic Data of Road Users	**Total Injured**		**Death**		**CFR * (%)**
	Number (*n* = 268)	**%**	**Number (*n* = 59)**	**%**	
Sex					
Female	165	61.6	32	54.2	19.4
Male	103	38.4	27	45.8	26.2
Male:Female	1:1.6		1:1.2		
Age-groups (year)					
<15	63	24.9	10	16.9	15.9
15–19	27	10.7	8	13.6	29.6
20–24	22	8.7	3	5.1	13.6
25–29	25	9.9	9	15.3	36.0
30–34	16	6.3	3	5.1	18.8
35–39	9	3.6	3	5.1	33.3
40–44	21	8.3	8	13.6	38.1
45–49	18	7.1	5	8.5	27.8
50–54	18	7.1	4	6.8	22.2
55–59	11	4.3	3	5.1	27.3
≥60	23	9.1	3	5.1	13.0
Total	253	100.0	59	100.0	23.3
Mean age (year)	31.1		32.0		
Minimum age (year)	3 months		3 months		
Maximum age (year)	88		82		
Vehicle used by casualties					
Motorcycle	1	0.4	1	1.7	100.0
Motorcycle with sidecar	2	0.8	0	0.0	0.0
Car	28	10.8	18	31.6	64.3
Pickup	133	51.6	28	49.1	21.1
Van	26	10.1	7	17.5	26.9
Ambulance	8	3.1	1	12.3	12.5
Bus	58	22.5	1	1.7	1.7
Truck	2	0.4	1	1.7	50.0
Total	258	100.0	57	100.0	22.1
Types of injured					
Driver	29	10.8	11	18.6	37.9
Passenger	229	85.5	46	78.0	20.1
Pedestrian	10	3.7	2	3.4	20.0
Total	268	100.0	59	100.0	22.0

Table 3. *Cont.*

Demographic Data of Road Users	Total Injured		Death		CFR * (%)
	Number (*n* = 268)	%	Number (*n* = 59)	%	
Body region of injuries (multiple response)					
Head/neck (include middle inner ear)	111	41.4	45	76.3	40.5
Face (include eye balls)	51	19.0	10	16.9	19.6
Thorax (Chest)	58	21.6	21	35.6	36.2
Abdominal or pelvic contents	46	17.1	11	18.6	23.9
Extremities or pelvic girdle	118	44.0	29	49.1	24.6
External and body surface	95	35.4	19	32.2	20.0

* case fatality rate.

Place of Deaths

Figure 2 presents places where death occurred. The majority of deaths were death at the scene with 39 persons (66.1%), followed by death in a hospital with 16 persons (27.1%).

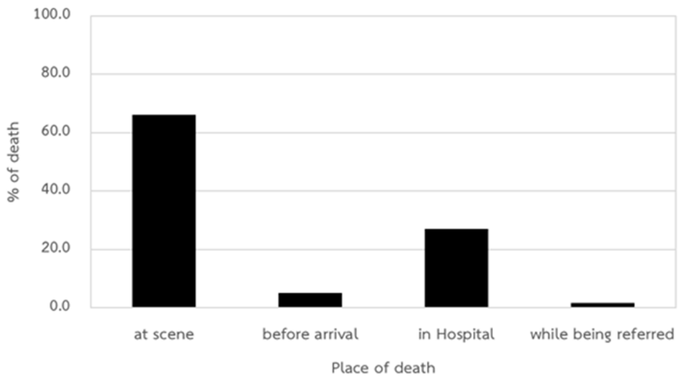


Figure 2. Bar chart percent of deaths by places of deaths.

4.3. Prehospital Care System

The first call to the scene in the case of a serious injury accident was the Medical Emergency Call (1669), 11 events (44.0%), followed by Police Call (191), 9 events (36.0%), and District Hospital/FR in the area, 5 events (20.0%).

Table 4 shows that the transportation from scene had many teams or many bystanders in each event: 84 percent of the injured persons had been transferred to the hospital by first response units (FR) and 76 percent of these persons were transferred by hospital EMS.

4.4. Prehospital Care System

More than half of the accidents overall involved 4 risk factors, 14 events (56.0%), followed by 3 risk factors, 10 events (40.0%). All accidents involved a combination of human error in conjunction with physical environment risk factors. Vehicle defects were a risk factor in 84.0% of the accidents. All road traffic accidents which caused injury involved a combination of human errors in conjunction with vehicle defects. Physical environment defects were a factor in 96.0% of injury causing accidents.

Table 5 shows the Haddon's matrix analysis of risk factors in three crucial stages of road traffic injuries. In the pre-event phase, speeding was the most common human error, accounting for 17 events (68.0%). Fixed objects in the safety zone were a physical environment defect for 15 events (60.0%), and accident black spots were a social-economic environment defect involved in 12 events (48.0%). In the event phase, the human error of not using the safety belt and being ejected from the seats or the vehicles was the most common in causing road traffic injuries. A vehicle hitting fixed objects in safety zones was found among most road traffic injuries. In the post-event phase, delayed calls to EMS and the lack of persons trained in first aid on scene were found to be the largest contributor to injury risk.

Table 4. Number and percent of the mode of transportation of the injured from scene (multiple response).

The Transportation from Scene (Multiple Transportations)	Bystander	Police Officer	First Response Unit (FR)	Hospital EMS (BLS/ALS)	Total
(Event 1) An excursion bus overturned		✓	✓	✓	3
(Event 2) A car burning after hitting a tree			✓		1
(Event 3) A school pickup running off a road and crashing into a tree	✓		✓	✓	3
(Event 4) A car burning after hitting a tree			✓	✓	2
(Event 5) A car hitting a tree		✓			
(Event 6) A saloon car crashing into a utility pole			✓	✓	2
(Event 7) A public transport pickup running off a road and crashing into a utility pole			✓	✓	2
(Event 8) A prime mover truck crashing into a pedestrian bridge				✓	11
(Event 9) An overturned bus crashed into trees after hitting a pedestrian			✓	✓	2
(Event 10) A chartered van crashing trees and overturning		✓	✓	✓	3
(Event 11) An excursion pickup public transport running off a road and crashing into trees	✓	✓	✓	✓	4
(Event 12) A pickup truck running off a road and crashing into a tree and a utility pole			✓		1
(Event 13) An armored pickup running off a road, crashing into trees, and overturning	✓	✓			2
(Event 14) An ambulance crashing a car, crashing into six pedestrians			✓	✓	2
(Event 15) A car u-turned, crossed into the opposite lane, and crashed into a worker pickup truck, overturning and running off the road			✓	✓	2
(Event 16) An ambulance crashing into the back of a prime mover truck			✓	✓	2
(Event 17) A school pickup crashing into a tree and overturning after a car crashed into the pickup		✓	✓	✓	3
(Event 18) A pickup crashing into a motorcycle			✓		1
(Event 19) A pickup truck crashing a public van, running off the road, and hitting trees			✓	✓	2
(Event 20) A truck crashing into a worker pickup truck, running off the road, and hitting two trees and a utility pole			✓	✓	2
(Event 21) A pickup crashed into other pickups before the second pickup rolling and flipping over a passenger	✓	✓	✓		3
(Event 22) A car crashing into an ambulance then crashing into a pickup				✓	1
(Event 23) An excursion bus crashing into the back of another excursion bus, crashing into the back of a pickup			✓	✓	2
(Event 24) A car crashing into a pickup and running off the road, colliding with a prime mover truck			✓	✓	2
(Event 25) A multiple-vehicle crash in front of a school zone		✓	✓	✓	3
Total	4 (16.0%)	8 (32.0%)	21 (84.0%)	19 (76.0%)	52 (100.0%)

Table 5. Haddon's Matrix analysis risk factors of injuries from the 25 events of in-depth road traffic investigations.

Event Phases	Influencing Factors of Injuries			
	Human	Vehicle	Environment	
			Physical	Social-Economic
Pre-event	**Driver** -Speeding *(Event 2, 3, 4, 5, 6, 8, 9, 10, 12, 13, 14, 16, 17, 18, 19, 20, 23, 24)* -Drowsy (fatigue, usually from long driving time, night driving, long-distance driving) *(Event 2, 6, 7, 8, 10, 12, 13, 16, 21, 24)* -Decision (try to avoid pedestrian suddenly, sudden change of lane, suddenly braking) *(Event 1, 9, 14, 18, 22, 23, 25)* -Inexperience (not regular vehicle), Lack of ambulance driving training, unlicensed driving, more frequent accidents, downhill braking, brake immediately) *(Event 1, 4, 11, 13, 14, 15, 16, 22, 23, 24, 25)* -Driver's health (type 2 diabetes) *(Event 7)* -Used alcohol/drug *(Event 7, 12)* -Distracted driving (two small children sat next to the driver, impaired shoes, bent down to pick up things) *(Event 6, 15, 16)* -Traffic behavior/skill (not enough distance between vehicle, drive on the right of way, driving with one hand, slow down a car with gears when speeding) *(Event 2, 3, 18, 20, 23)* **Pedestrian** -Elder walking on road *(Event 9)*	**Car** -Overloaded *(Event 6, 21, 24)* -Mismatches tires (tires age) *(Event 6)* -Second hand car/no car insurance, no car tax *(Event 2)* **Pick up** -Overloaded *(Event 3, 11, 15, 17, 20, 21, 25)* -Modifications (for public songthaew, school songthaew, private transportation, platform at rear pickup) *(Event 3, 7, 11, 12, 13, 20)* -Mismatched tires (tires age) *(Event 3, 11, 13)* -Vehicles older than 20 years *(Event 12)* - No car insurance, no car tax *(Event 3, 12)* **Ambulance** -Modifications (the radio wire leaned across the drink holder in front of the console) *(Event 16)* **Bus** -Overloaded *(Event 1)* -Not available (in repair) *(Event 1)* -Tire no tread *(Event 9)* -Out of control *(Event 9)* **Truck** -Overloaded *(Event 8)* -Out of control *(Event 25)*	-Drenched road/Slippery road *(Event 17, 18, 19, 25)* -Two-lane road *(Event 9, 21)* -Four-lane, no road medians *(Event 6)* -Road surface *(Event 19)* -Dim lighting conditions, no traffic lights *(Event 2, 5, 8, 9, 10, 16)* -No guard rails *(Event 2, 4, 6, 8, 24, 25)* -Different road curb *(Event 9, 11, 21)* -Fixed objects in safety zone (trees, cement drainage pipe, utility poles) *(Event 2, 3, 4, 5, 6, 9, 10, 11, 12, 13, 16, 17, 19, 20, 25)* -No shoulder line demarcations *(Event 21)* -Traffic mix (entrance school, U-turn, end of curve road,) *(Event 14, 25)* -Mixed horizontal and vertical curves *(Event 17)* -Downhill *(Event 1)* -The branches obscured the vision *(Event 14, 22)*	-Accident black spot in this area *(Event 2, 3, 10, 12, 13, 14, 16, 17, 18, 19, 20, 23)* -Lack of pedestrian facilities (footpath, pedestrian crossing, overpass) *(Event 9, 14, 25)* -No traffic signs *(Event 1, 3, 6, 9, 13, 16, 20, 23, 25)* -a community (house, buying food, funeral on the roadside) *(Event 9, 18)* -School zone (Street food vendors, students, vehicle parking) *(Event 25)* -Roadside market *(Event 14)* -Main road to Malaysia *(Event 25)* -Many heavy vehicles pass *(Event 25)* -Road under construction *(Event 23)* -Renting a bus for excursions *(Event 1, 23)*

Table 5. *Cont.*

<table>
<tr><th rowspan="3">Event Phases</th><th colspan="4">Influencing Factors of Injuries</th></tr>
<tr><th rowspan="2">Human</th><th rowspan="2">Vehicle</th><th colspan="2">Environment</th></tr>
<tr><th>Physical</th><th>Social-Economic</th></tr>
<tr><td>Event</td><td>**Driver**
-Non use of seat belt (hit other objects in vehicle, ejected from vehicle) *(Event 3, 10, 11, 12, 13, 15, 21, 23, 25)*
-Used seat belt wrong position *(Event 21)*
-No warning sign *(Event 25)*
- Hit other objects in vehicle *(Event 4, 5, 8, 18, 19)*
Passenger
- No use of seat belt (dislodged from seat, hit other objects in vehicle, ejected from vehicle) *(Event 1, 2, 3, 4, 5, 6, 9, 10, 12, 13, 14, 16, 17, 19, 20, 21, 22, 23, 24, 25)*
- Sat in the spec-cab and rear of pickup *(Event 3, 7, 11, 12, 15, 17, 20, 21, 25)*
- Sat in a third bench in the middle of seating area *(Event 25)*
- Stood on rear platform *(Event 25)*
- No self-defense (dislodged from seat, ejected from vehicle) *(Event 1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 14, 15, 16, 20, 21, 22, 23, 24, 25)*
-Ejected from cargo *(Event 3, 6, 8, 9, 10, 12, 13, 15, 16, 17, 19, 20, 21, 25)*
-Jump from vehicle *(Event 25)*
-Children sat near side winder and sat in front of vehicle *(Event 6, 24)*
-Many passengers *(Event 1, 3, 6, 11, 15, 17, 20, 21, 24, 25)*
-The helmet slips from the head *(Event 18)*
Pedestrian
-Elder walking on road *(Event 9)*
-People walking on the median strip on the road (include children) *(Event 14)*
-Walking and standing on shoulder of road *(Event 25)*</td><td>**-Vehicles without occupant restraints** (seat belts, child restraint, air bag)
(Event 1, 3, 6, 7, 10, 11, 12, 15, 17, 20, 21, 24, 25)
Motorcycle
-Head-on crash *(Event 18)*
Car
-Head-on crash *(Event 2, 24)*
-Sideswipe accident *(Event 6, 15)*
-Structural damage *(Event 2, 4, 5, 6, 15, 24)*
-No child seat belts *(Event 6, 24)*
-No air bag *(Event 5)*
Pick up
-Head-on crash *(Event 3, 7, 11, 12, 21)*
-Fell down and rolled over *(Event 21)*
-Rolled over and overturned *(Event 13, 15, 20, 21)*
-Rear impact *(Event 25)*
-Structural damage *(Event 3, 7, 11, 12, 13, 15, 18, 20)*
-No occupants safety (airbags, seat belts, cargo safety) *(Event 3, 7, 11, 12, 13, 15, 17, 20, 21, 25)*
-Non-working seat belt in the front seat *(Event 21)*
-Seat not fixed (bench seats) (*Event 3, 11, 20, 25)*
Ambulance
-Rear impact with car, truck *(Event 14, 16)*
-Sideswipe accident *(Event 22)*
-Structural damage *(Event 16)*
-Rolled over *(Event 16)*
Van
-No child seat belts *(Event 10)*
-Overturned *(Event 10)*
-Structural damage *(Event 10, 19)*
-Seat belt not fixed *(Event 19)*
Bus
-Rear impact with bus *(Event 23)*
-Overturned *(Event 1, 9)*
-Seats dropped *(Event 1, 9)*
-Frame damage *(Incident 1, 9)*
-No seat belt *(Event 1)*
Truck
-Structural damage *(Event 8)*</td><td>-The body impacted ground *(Event 6, 9, 10, 12, 13, 14, 17, 20, 21, 25)*
-The body impacted the fixed objects *(Event 20)*
-Crashed into trees *(Event 2, 3, 4, 5, 9, 11, 12, 13, 14, 16, 17, 19, 20, 24, 25)*
-Crashed into other fixed objects (utility pole, kilometer pillar, pedestrian bridge *(Event 4, 6, 7, 8, 12, 20)*
-Flipped over to the floor (Event 21)
-Median barrier could not stop vehicle *(Event 15, 24)*
-Dusty road *(Event 23)*</td><td>-No light sign on roadside *(Event 9)*
-During school closing times: *(Event 25)*
-School zone *(Event 8, 25)*
-Community zone *(Event 9, 18, 23)*
-Market zone *(Event 14)*</td></tr>
</table>

Table 5. *Cont.*

Event Phases	**Influencing Factors of Injuries**			
	Human	**Vehicle**	**Environment**	
			Physical	**Social-Economic**
Post-event	-No one trained in first aid on scene/first aids on scene bystander *(Event 1, 2, 3, 4, 5, 6, 10, 11, 13, 15, 16, 17, 18, 21, 23)* -Delayed call to EMS/unavailable/no contact *(Event 2, 3, 4, 5, 6, 11, 13, 15, 16, 18, 21, 24, 25)* -Delayed first aids of paramedics *(Event 3, 6, 10)* -No emergency response plan/delay in emergency response plan *(Event 1, 11, 15, 17)*	**Sidecar** -Over the body *(Event 21)* **Car** -Burn in car *(Event 2, 4, 24)* -Stuck in vehicle *(Event 4, 6, 24)* -Over the body's pedestrian *(Event 14)* **Pick up** -Over the body *(Event 17, 21)* -Stuck in vehicle *(Event 3, 8, 13, 20)* -Burn in car *(Event 13)* **Ambulance** -Burn in car *(Event 16)* -Stuck in vehicle *(Event 16)* **Van** -Stuck in vehicle *(Event 10, 12, 19)* -Seat over the body *(Event 10)* **Bus** -Stuck in vehicle *(Event 9, 23)* -Door obstructed *(Event 1)* **Truck** -Stuck in vehicle *(Event 8)*	**Ease of access** -Difficult to access and evacuate victims (traffic jam, crowd) *(Event 6, 7, 8, 11, 12, 14, 15, 19, 20, 23, 25)* -Accident redundant *(Event 19)*	-lack of slitting equipment *(Event 8, 9)* -No coordination between EMS center and local team *(Event 3, 6, 7, 8, 17, 21, 25)* -EMS team not registered *(Event 25)* -Unclear notification to EMS center and local team *(Event 15, 17)* -Confused information between EMS center and local team *(Event 17)* -Poor coordination between hospital and ambulance *(Event 1, 11, 17, 22, 23)* -Lack of communication device in ambulance *(Event 17, 22, 23)* -No incident commander on scene *(Event 1, 15)*

5. Discussion

The reviews of 25 in-depth road injury investigations presented here reveal some of the common patterns and risk factors connected to the major problem of road injuries in Thailand. The Haddon matrix approach provided a useful tool to examine the multiple factors connected to injury and the severity of injury in physical and temporal dimensions. This adds much to the previous literature focusing on mainly driver behavior or other singular risks.

The study found that road traffic injuries and deaths occurred most often among those aged less than 30 years, which is in accordance the World Health Organization's analyses [2]. Rather than most crashes having a singular explanatory factor, it was how multiple factors interrelated with each other that caused the most injury risk. The key findings were that fatigue, speeding, and inexperience behind the wheel were the most important drivers of crashes, but that these were exacerbated when drowsy, speeding, or inexperienced drivers encountered fixed roadside objects and other road hazards, particularly in known accident blackspots.

The most important pre-event risk factors found in this study confirmed other research in terms of human errors, vehicle defects, and environment defects [15,28,41,42]. The work of multidisciplinary road traffic investigation teams were important keys to recognizing human errors increasing risk pre-crash, including the behavior of drivers (speeding, drowsiness from night or long-distance driving, insufficient driving skills) and the risk behaviors of others (insufficient understanding of traffic rules, risk behaviors of pedestrians or passengers). This study confirmed that exceeding the speed limit was the most common violation involved in road accidents [17,19,20,42] and led to more severe injuries [19,33]. Moreover, drowsy drivers appear widespread as has been found in several countries [19,21,22].

The vehicle defects causing the pre-crash consisted mainly of overloading and modification [32]. The environmental defects pre-event were documented as many fixed objects in the safety zone, no traffic lights, no guard rails, and no traffic signs. It was also worth noting that there have been frequent crashes at these accident blackspot areas. This study is similar to observations in other studies [18,31]. However, this study showed that multiple risk factors at the pre-crash phase lead to the severity of traffic accidents at that time more than any single risk factor such as "high speed in the presence of overloading and fixed objects in safety zone", "high speed while distracted in spite of overloading and fixed objects in safety zone", "high speed in spite of drowsiness from night driving and long-distance driving together with overloading and fixed objects in safety zone", " high speed while bent down to pick up things on floor", and "distracted driving from impaired shoes which go against the accelerator while U-turn".

In terms of actual event-related factors, this study showed that most accidents and injuries are caused by human-related factors. Moreover, the presence of vehicular risks and environmental risks involved vehicles leaving the road and collisions with roadside hazards. This pattern has also been found in other in-depth road traffic analyses [29,34,35,43]. Moreover, the pickup was the most common vehicle type in road traffic accidents and was associated with the most injuries and deaths [18,23,30]. The severity of injuries and fatalities were also linked to the number of occupants in the vehicles, as found elsewhere [29,44], and carrying passengers in the cab and cargo area [24–26,30]. These risk factors could be preventable by enforcing the law more rigorously, coupled with the consideration of the use of state-of-the-art technology to help monitor real-time risky behavior.

Then, multiple inter-related risk factors at the crash phase led to the severity of traffic injuries. Event-based human error involved the non-use of seat belts, sitting in a place without safety devices such as the cargo area and the cab of the pickups, and being ejected from seats or vehicles. Similar event stage risk factors have been observed in other studies [24,25,27,30,45,46]. The severity of injuries and fatalities were also linked to the number of occupants in the vehicles, as found elsewhere [34], and carrying passengers in the cab and cargo area [24–26]. In fatal accidents, most victims died at the scene. Head or neck trauma was the main cause of death [47,48].

Post-crash, a further set of risks affected the severity of injury. The important post-crash risk factors were reported as not having any persons trained in first aid at the scene, delayed calls to EMS, or the non-availability of EMS. Fatality and disability resulting from accidents was also associated with other post-event factors, including being stuck in vehicle, flames in the car, vehicle over the body, difficulty to access and evacuate victim, and a lack of slitting equipment. This phase is important to reduce fatalities and disabilities [28]. The state of the art of real-time traffic accidents should be considered to monitor traffic flow after post-impact [13].

Searching for in-depth information on all elements of the road injury is important for finding the root cause of the problem, where the immediate injury may be just the tip of the iceberg [49–51].

The analyses presented in this paper provide clear avenues for Thai policymakers to improve road safety in Thailand at multiple levels. The results provide an opportunity to develop holistic road safety strategies that address the multi-level determinants of injury. The results can also be relevant to other low- and middle-income countries struggling with road traffic injury burdens.

There are some quite clear messages that can be applied to policies designed to improve traffic safety decision making. Recommendations include improvements in human risk behaviors, in terms of addressing drunk driving, speeding, helmet and seatbelt use, and fatigue. Physical road infrastructure should be improved through a more effective separation of road users from roadside objects. Safety standards for vehicles should also be addressed through more strict registration requirements and inspection regimes. Finally, post-crash outcomes could be improved through government support for higher rates of first aid training among the general population, and better coordination of EMS services. A holistic approach to road traffic accident prevention in Thailand can both reduce the injury rate and the severity of injuries incurred.

A limitation of this study was that it only considered the most serious road traffic incidents in the southern part of Thailand.

The research reported here identifies some of the most important combinations of human, vehicle, and environmental risks, which increases the risk of traffic injury and mortality in Thailand. Further research is needed to investigate the most effective methods to implement holistic road traffic prevention methods, identifying which combinations of interventions can be most effective in reducing the burden. The cataloguing and documenting of the riskiest physical infrastructure in each region, along with and investigating amelioration measures is also essential. The inclusion of road traffic injury experts in research into the most effective road design for new developments which can reduce injury risk is also critical.

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