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RESEARCH ARTICLE

Development of a traffic accident simulation system for main roads in Loei Province, Thailand: Application of a geographic information system and multiple logistic regression with clustering

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Abstract. Traffic accidents are a major and crucial problem worldwide. The development of a traffic accident simulation system applied by using a geographic information system and multiple logistic regression with clustering can provide drivers with safe routes as well as guidelines for assessing the risk points of accidents in each subdistrict. This research is based on case-control study design. The data were collected by using two types of questionnaires: a questionnaire for 35 community leaders and a questionnaire for 580 community residents based on the distance at which main routes pass through the subdistrict area. The data were analysed through multiple logistic regression with clustering, and the standardized coefficient of the selected variables was then added to the equation as a weight in the traffic accident simulation system. The results of the study indicated that 11 variables affected traffic accidents. These factors were evaluated in order to predict traffic accidents (Pseudo R square=0.5906). Standardized coefficient of variables was applied in a geographic information system to simulate traffic accidents on roads. This study was distinctive for its analysis, which examined the clusters of variables that were the subdistrict-level data, including surroundings and road conditions at the riskiest location in each subdistrict. The data were analysed based on their quality as subdistrict data clusters. The analysis results were then applied as the weight of variables used in the GIS to obtain the values appropriate to the data clusters' quality for the GIS to properly simulate traffic accidents in each area.

1. Introduction

Traffic accidents are a major problem worldwide. Every year, every country loses valuable human resources, as well as assets affecting the economy, society, and people's quality of life. According to a 2018 report by the World Health Organization (2018), approximately 1.35 million people are killed in traffic accidents every year, and traffic accidents rank as the 8th cause of death. According to the World Atlas website in 2017, Thailand topped the ranking as the country with the highest death rate in road accidents at 36.2 deaths per 100,000 population, followed by Malawi at 35 deaths per 100,000 population and Liberia at 33.7 deaths per 100,000 population (Laohavilai, 2017). In detail, 13,335 people died in traffic accidents in Thailand, and 835,527 injuries occurred (Puttarn, 2021). In 2019, Loei Province had the second-highest traffic accident-related death rate in the Northeast region, with a rate of 36.09 deaths per 100,000 population. The death rate was higher than the death rate nationwide in 2019 (29.90 deaths per 100,000 population) (Thai Health Promotion Foundation in Thailand, 2019), which was nearly equal to the number of traffic accidents in the world. Therefore, traffic accidents are a significant problem for which further solutions should be sought.

Traffic accidents are caused by many factors, including personal conditions, such as gender, age, and individual negligence (Kumeda et al., 2019); road conditions; and environmental conditions, such as road surface, electricity, weather conditions (Kumeda et al., 2019; Sori, 2019), and vehicle conditions (Sori, 2019). Each traffic accident can be caused by a combination of various factors, including people, vehicles, roads, and the environment. In analysing factors resulting in traffic accidents, the use of logistic regression analysis statistics is considered appropriate since the dependent variable is a multiple variable, and there are two possible values: having an accident and not having an accident. For independent variables, several variables are related to the dependent variable, and in each region, the independent variables are related to the different dependent variables. Therefore, to select independent variables that are related to the following variables for application design, a multiple logistic regression analysis is considered in this study. In addition, to create obvious benefits, a geographic information system is implemented to solve the problem of traffic accidents.

A geographic information system is a computerized information system for data input, manipulation, and analysis. It involves collecting, storing, retrieving, organizing, analysing, and expressing spatial relationships (Ondieki and Murimi, 1997) by using geographic features as a link between data. A report is presented in the form of a map of spatial data displaying the nature of the distribution of interesting various spatial data. In the past, several research reports have studied the use of geographic information systems to analyse traffic accidents (Umam et al., 2021; Audu et al., 2021). Some studies used geographic information systems with logistic regression statistics to analyse traffic accidents (Audu et al., 2021), and others were conducted by using geographic information systems in conjunction with logistic regression statistics to determine whether a point or area was safe (Rafita et al., 2016). However, none of these studies highlighted roads at local levels to design an application to find safe travel routes

To simulate safe travel routes in the context of Thailand, the researcher considered the routes divided by the subdistrict level since the administrative system in Thailand has subdistrict organizations with the authority to improve the environment to reduce the risk of traffic accidents. They can also coordinate with relevant agencies if road conditions need to be improved and can also be publicize issues to people in the area to reduce the risk of traffic accidents. The district is the smallest unit that can be managed to reduce the risk of traffic accidents in the area of responsibility. Therefore, this research involved the collection of data, including the environment and road conditions, at both the individual and subdistrict levels and led to an analysis adapting the clustering effect to the subdistrict and developing an application to simulate risk situations on roads in the subdistrict area. In addition, previous studies indicated that the use of logistic regression with the geographic information system mentioned above did not concern the clustering effect at the district level.

Since different factors affect traffic accidents in each area, multiple logistic regression with an adjusted clustering effect was analysed to be used as the weight in developing an application for traffic accident simulation to reduce travel risks, encourage drivers to be cautious, and enable subdistrict organizations to plan improvements of accident-prone locations to ensure road safety in areas under their responsibility. Therefore, multiple logistic regression with an adjusted clustering effect was analysed to be used as a weight in developing an application to simulate traffic accidents to reduce travel risks, to encourage drivers to be cautious, and to enable subdistrict organizations to plan to improve risk points to ensure road safety in areas under their responsibility. Therefore, this research aims to identify risk factors affecting traffic accidents and to develop a simulation system of traffic accidents on main roads in Loei Province, Thailand, by applying a geographic information system and multiple logistic regression with clustering, as is detailed in the following sections.

2. Methods

This study comprises research and development using a case-control study with the aim of 1) identifying risk factors affecting traffic accidents and 2) developing a simulation system for traffic accidents on the main roads in Loei Province, Thailand, by applying the geographic information system and multiple logistic regression with clustering. To identify the risk factors affecting traffic accidents, multiple logistic regression with clustering was used with variables associated with traffic accidents. The data collection period was between 1 August 2020 and 30 September 2021 (Thailand fiscal year).

The sample population in this study included those who lived in a subdistrict where the main road passed at a distance of no more than 500 metres. The sample size was determined to be approximately 20 times the number of independent variables (Leech et al., 2016): there were 29 independent variables, and the sample was 580 people. In each subdistrict, the number of victims collected was 10 times the number of independent variables (290 people), and the number of those who never experienced an accident was also 10 times the number of independent variables (290 people). Data collection in each district was proportional to the distance covered by the main roads. In addition, subdistrict-level data were collected from community leaders in all 35 subdistricts (1 person per subdistrict) through which the main road passes

The researchers submitted the research project and research tools to the Research Ethics Committee of Loei Rajabhat University for consideration and certification. Thirty sets of data were collected from the questionnaire trial among people living on the main roads in Nong Bua Lamphu Province. Additionally, the quality of the tools was analysed, and the questionnaire was modified. The data were collected by the researcher and the research assistant, who administered the questionnaire to the respondents and collected data from 35 sets of community leaders (1 set per subdistrict) and 580 sets of people in the subdistrict. The projection of the aforementioned sample groups was correct. The completed questionnaires were checked for completeness of data and used to record the data for further analysis.

The general data analysis of the respondents is based on descriptive statistics, whereas qualitative data are presented as frequencies and percentages. For quantitative data with a normal distribution, the mean and standard deviation are presented. For abnormally distributed data, median, maximum, and minimum values are presented. The analysis for identifying risk factors affecting traffic accidents was conducted by using multiple logistic regression with clustering via STATA version 16 (This research used backward method to select only the variables affecting traffic accidents on the main roads in Loei Province (There are several selection methods, including stepwise selection, enter selection, backward selection, and forward selection. The researchers tested each method and found that backward selection was the most suitable for the data sets. Consequently, the results from the analysis with backward selection were applied as the weight of colours in GIS for simulating traffic accidents in the following step).

To develop a traffic accident simulation system, the standardized coefficient of the independent variables selected into the equation from multiple logistic regression with clustering was weighted to calculate the traffic risk score. The scores were set by the research team to be between 0 and 5 based on the principle of normalization, calculated from the equation as follows:

$$S = \left[\frac{\sum_{i=1}^{n} k_i F_i}{\sum_{i=1}^{n} k_i}\right] . M \quad (1)$$

Where S indicates traffic accident risk score, M indicates maximum score = 5, n represents the number of independent variables in the equation obtained from analysing multiple logistic regression with clustering, k represents the standardized coefficient of each independent variable, and F represents the value of the independent variables (equal to 0 or 1)

After calculating the traffic accident risk score from Equation (1), the researchers defined each risk range colour for the map presentation in the geographic information system (red, yellow, violet, blue, green).

The application development was developed by using Visual Studio 2017 together with the MapWinGIS version 5.3.0 program.

3. Result and Discussion

The results of the analysis of environmental data and traffic lights for the highest risk points in each subdistrict from the questionnaire of community leaders in 35 subdistricts were as follows: no smoke/dust, 85.7%; no fog, 71.4%; frequent rainfall, 57.1%; unclear weather, 88.6%; no traffic lights, 94.3%; flashing lights on the road, 51.4%; road lights, 51.4%; warning signs, 85.7%; no warning colour on the road surface, 82.9%; no washboard surface, 94.3%; and no flashing lights on the road surface, 94.3%.

The results of the personal data analysis indicated that of the victims at the times of the accidents, 66.9% used motorcycles, 59.3% were male, 51.7% were aged between 35 and 59 years (Mean=42.42, SD=15.28), 65.2% were married, 41.1% were uneducated, 33.1% were farmers, 84.1% were in normal physical condition, 79.7% had an abnormal emotional state, 88.3% lacked knowledge of traffic rules, 53.1% had a bad attitude about traffic, 82.1% were driving in normal conditions, 57.6% were driving unsafely and illegally, 91.4% were performing distracted activities while driving, 66.2% were using personal safety equipment, 54.1% had abnormal vehicle conditions, 57.2% had no driving licence, 86.9% had vehicle insurance, and 75.9% had life insurance.

The analysis of multiple logistic regression with clustering using backward selection indicated that 11 independent variables were suitable for the regression equation (p-value<0.05), namely, fog, cloudy weather, lack of lighting, male gender, abnormal physical condition, abnormal emotional state, unsafe driving and illegal driving, performing distracted activities while driving, no use of personal safety equipment, abnormal condition of vehicle, and having no driving licence, as detailed in Tables 1 and 2. The standardized coefficient in Table 6 will be used to develop the application in the next stage.

Table 2. Variables selected for the regression equation using multiple logistic regression with clustering

Variables	Univariate analysis				Multivariate analysis			
	cOR	95% CI		p	aOR	95% CI		p
Fog	1.00	0.71	1.41	1.000	1.96	1.05	3.67	0.034
Unclear weather	1.00	0.61	1.63	1.000	2.30	1.33	4.01	0.003
No road lighting	1.00	0.71	1.41	1.000	1.83	1.06	3.17	0.030
Male	2.16	1.53	3.04	<.001	1.84	1.04	3.26	0.036
Abnormal physical condition	18.04	5.67	91.44	<.001	9.83	2.11	45.79	0.004
Abnormal emotional state	90.70	46.47	187.83	<.001	111.06	53.71	229.64	<.001
Unsafe or illegal driving	3.29	2.22	4.91	<.001	3.66	1.68	8.01	0.001
Performing distracted activities while driving	1.41	0.79	2.53	0.216	7.18	2.90	17.82	<.001
Driving without using personal safety equipment	2.13	1.44	3.18	<.001	2.37	1.23	4.58	0.010
Abnormal vehicle condition	3.32	2.31	4.79	<.001	3.46	1.92	6.24	<.001
No driving licence	1.34	0.95	1.88	0.080	2.03	1.20	3.42	0.008

Notes: cOR is crude odds ratio, aOR is adjusted odds ratio. Pseudo R^2=0.5906

Table 2. Standardized coefficient of variables selected for regression equation using multiple logistic regression with clustering

Variables	Cluster variables	Standardized coefficient	Z	p
Unclear weather	Yes	0.8351	2.96	0.003
Foggy	Yes	0.6752	2.12	0.034
No road lighting	Yes	0.6051	2.16	0.030
Abnormal emotional state	No	4.7101	12.71	<.001
Abnormal physical condition	No	2.2852	2.91	0.004
Performing distracted activities while driving	No	1.9718	4.25	<.001
Unsafe or illegal driving	No	1.2987	3.26	0.001
Abnormal vehicle condition	No	1.2409	4.12	<.001
Driving without using personal safety equipment	No	0.8640	2.57	0.010
No driving licence	No	0.7059	2.65	0.008
Male	No	0.6116	2.10	0.036

$$S = \left[\frac{0.6752F_1+0.8351F_2+1.2409F_3+0.6116F_4+2.2852F_5+4.7101F_6+1.2987F_7+1.9718F_8+0.8640F_9+0.6051F_{10}+0.7059F_{11}}{0.6752+0.8351+1.2409+0.6116+2.2852+4.7101+1.2987+1.9718+0.8640+0.6051+0.7059}\right].5$$

For the analysis of multiple logistic regression with clustering when replacing equation (1) with a standardized coefficient, the result was as follows:

Where S means traffic accident risk score, F_1 indicates fog, F_2 indicates cloudy weather, F_3 indicates no road lighting, F_4 indicates male gender, F_5 indicates abnormal physical condition, F_6 indicates abnormal emotional state, F_7 indicates unsafe driving or illegal driving, F_8 indicates performing distracted activities while driving, F_9 indicates driving without using personal safety equipment, F_{10} indicates abnormal condition of vehicle, and F_{11} indicates no driving licence.

A traffic accident simulation with the software developed by Microsoft Visual Studio 2017 and MapWinGIS version 5.3.0 is shown in Figures 1 and 8.

When determining independent variables affecting traffic accidents, the 11 independent variables selected by multiple logistic regression with clustering were as follows: 1) Unclear weather. Hammad et al. (2019) pointed out that unclear weather is a risk factor affecting traffic accidents. Unstable weather can block visibility on the road, raising the risk of accidents. For example, cloudy weather during the day reduces route visibility and increases the risk of traffic accidents. 2) Fog. The study also agreed that fog is a risk factor for traffic accidents because it reduces visibility (Hammad et al., 2019). Due to poor visibility conditions, vehicles can fall or slide off the side of the road, collide with obstacles, or crash into other vehicles behind them or oncoming vehicles. 3) 3) Absence of road lighting. Song et al. (2019) concurred that a lack of road lighting contributes to traffic accidents. Without road lighting, visibility of the road and surroundings decreases, especially at night or even during the day under unclear conditions, which increases the risk of traffic accidents. 4) Abnormal emotional states such as anger, sadness, and frustration. These abnormal emotions are a risk factor for traffic accidents (Dianye et al., 2018) because emotional states affect the driver's driving ability. Drivers suffering from unusual emotional conditions

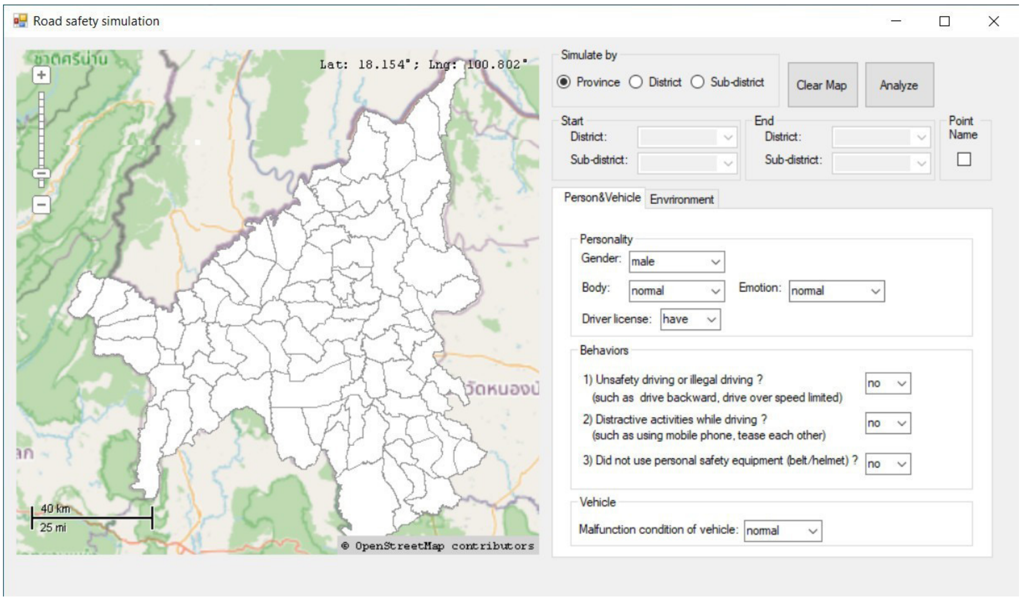

Figure 1. The first page of traffic accident simulation system

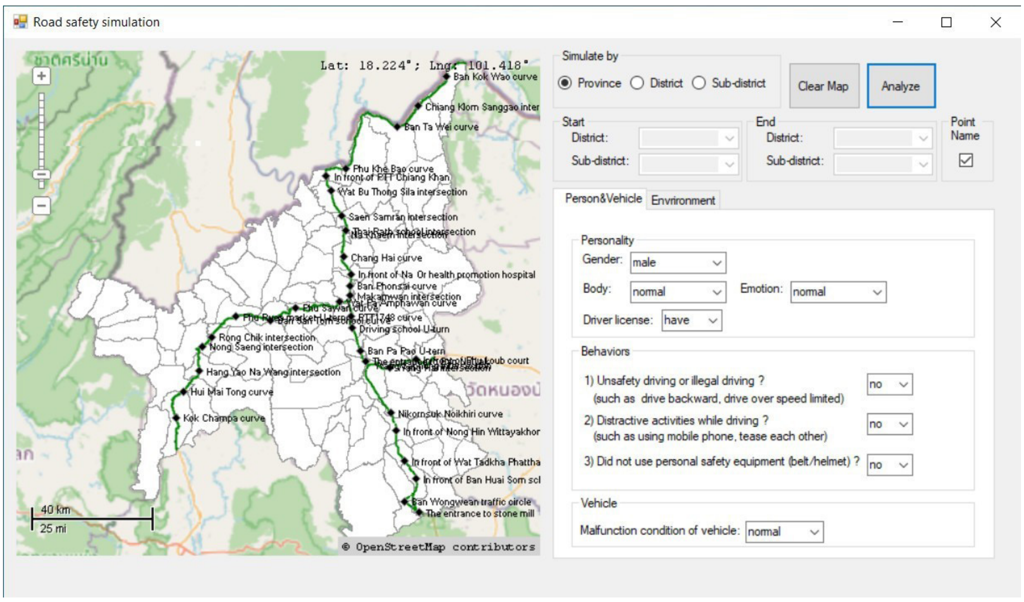

Figure 2 .Traffic accident simulation system on roads whole province

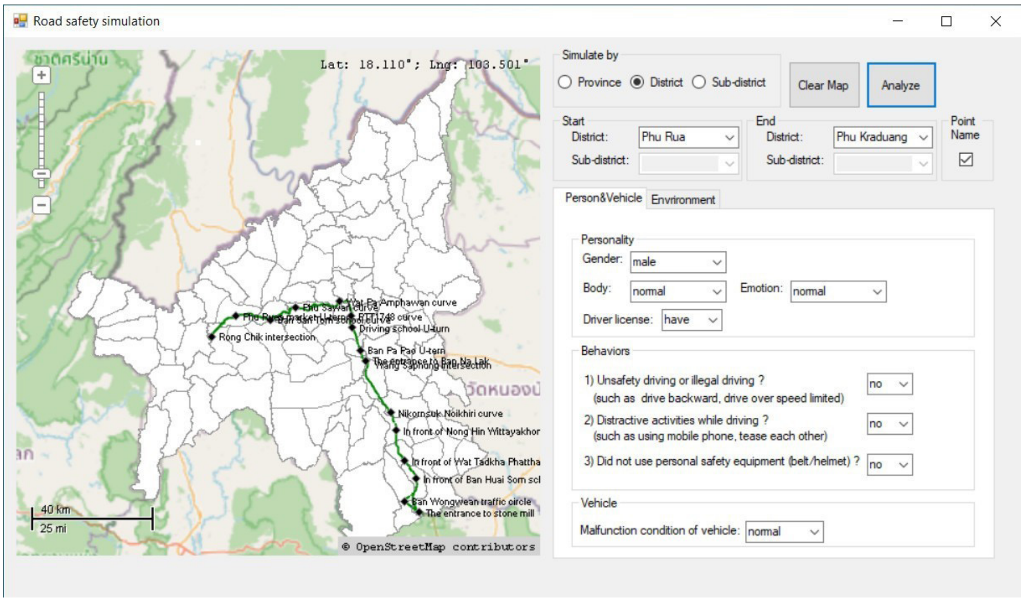

Figure 3. Traffic accident simulation system on roads between districts

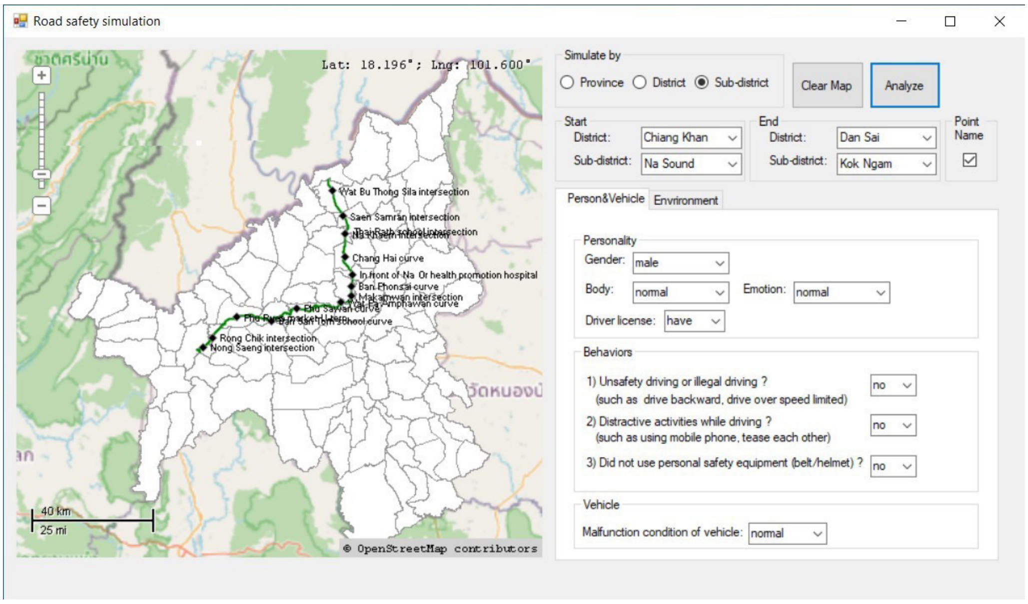

Figure 4. Traffic accident simulation system on roads between sub-districts

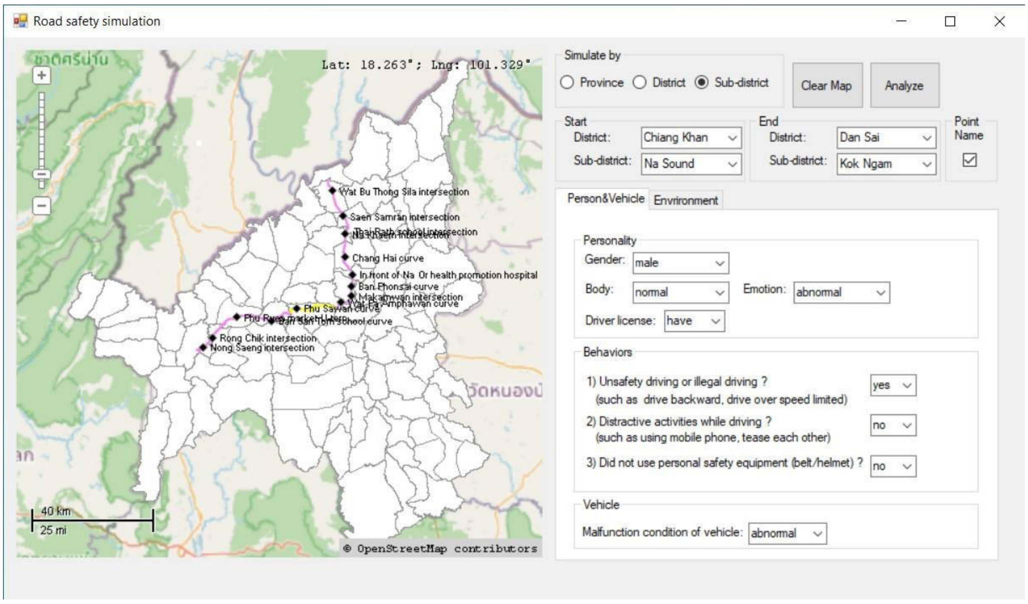

Figure 5. Adjustment of variables according to the condition of riders and vehicles

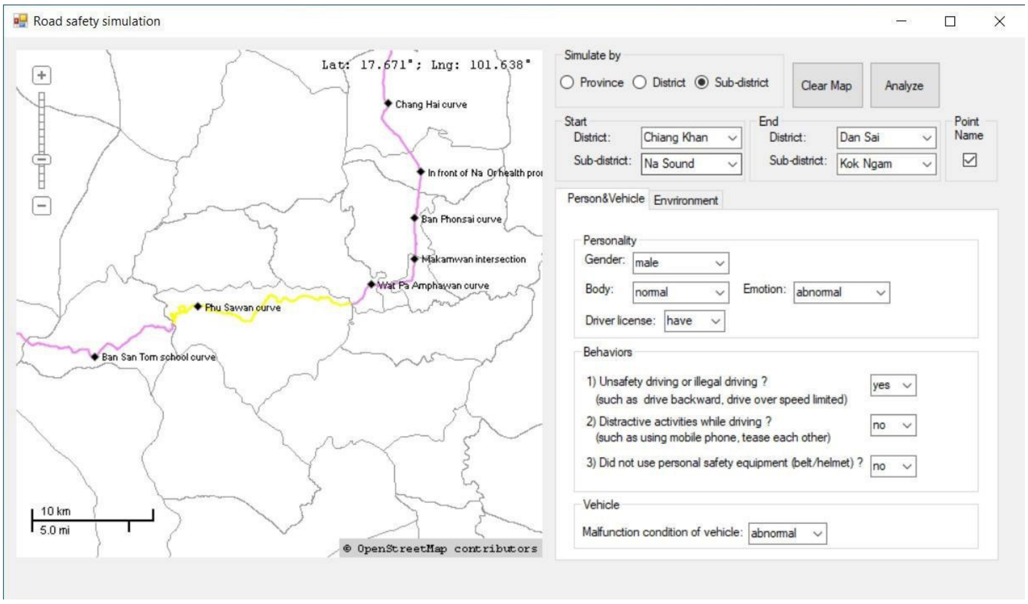

Figure 6. Zoom in the map on the high-risk roads

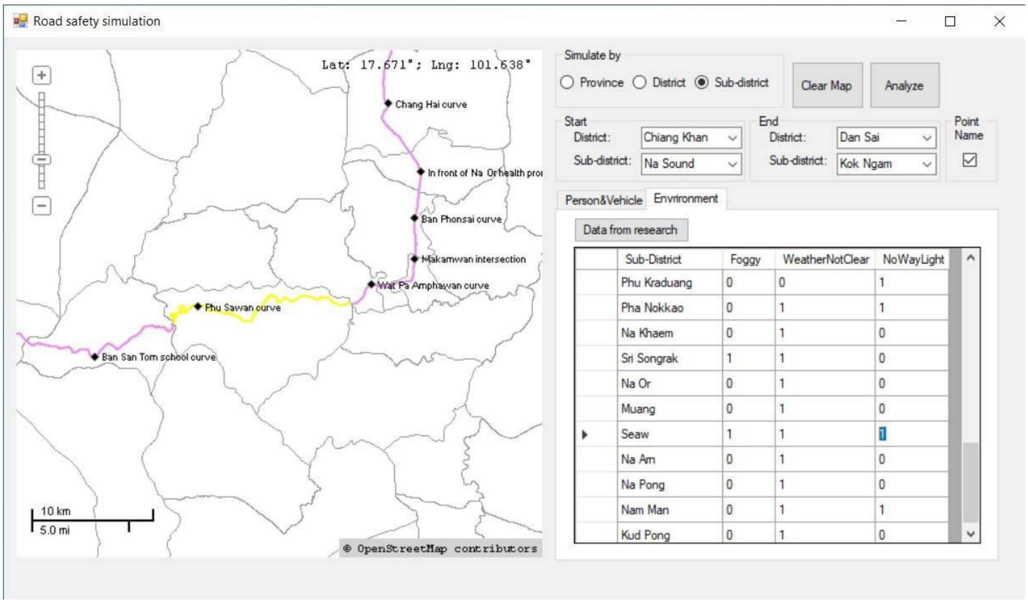

Figure 7. Tap to adjust the values of the variables of road and environment conditions

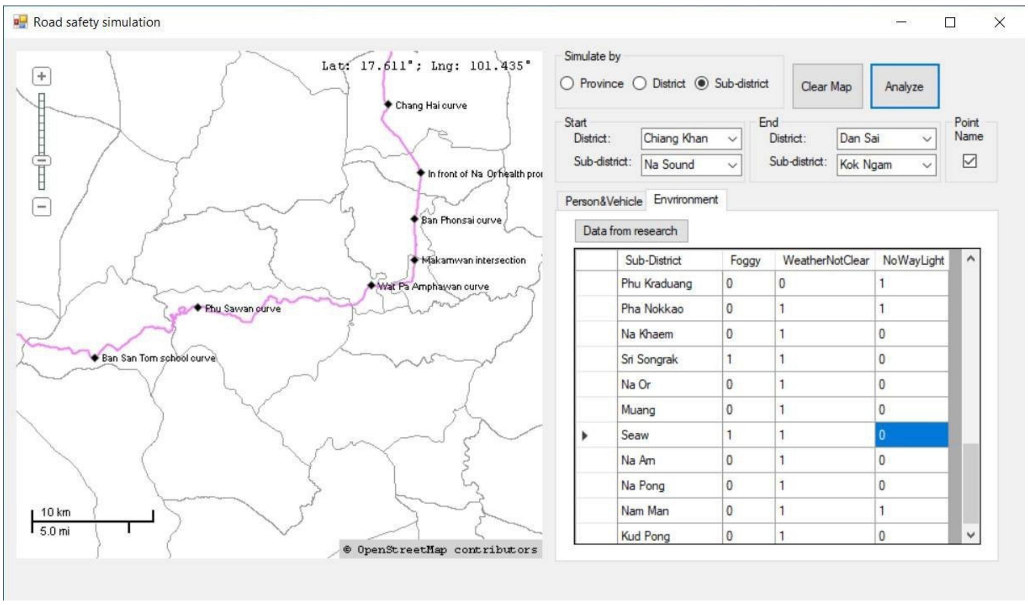

Figure 8. The results of the variable value adjustment of road and environment conditions

may be less cautious behind the wheel as their consciousness is focused on their emotions and what makes them feel that way. As a result, when concentration on driving is reduced, the likelihood of a traffic accident increases. 5) Abnormal physical condition. Examples include sickness or physical disability. Research supports that this is a risk factor affecting traffic accidents (Wang et al., 2019). A physical illness or physical disability impairs the driver's ability to drive. This is especially true in situations where emergency decisions are required, such as responding to vehicles, people, and animals or being cut off in front. An imperfect physical condition can also slow decision-making that requires the use of hands and feet. This can result in a traffic accident and increase the intensity of the situation when a traffic accident occurs later. 6) Engaging in distracting activities while driving, such as using a phone or playing with others. Wachnicka and Kulesza (2020) confirmed that this is one of the risk factors for traffic accidents. Using a phone or playing with others while driving reduces the driver's concentration. Drivers pay attention to conversations on the phone or with friends in the vehicle rather than the road, which can lead to accidents when a person, a vehicle, or an animal appears in front of them, including in dangerous environments or road conditions. A decision made to solve a driving problem during an incident, such as turning the steering wheel or stepping on the brake, can also go wrong and result in an accident. 7) Unsafe or illegal driving, such as driving too close behind another vehicle, driving in reverse, or cutting off the vehicle in front. Atreya et al. (2021) recognised this as a risk factor influencing traffic accidents. Each unsafe or illegal driving behaviour has a different impact on traffic accidents, including the severity of the accidents. When a vehicle is too close to another, it has difficulty slowing down and stopping when necessary. If the vehicle in front slows or stops abruptly, the vehicle following too closely will not be able to come to a complete stop in time to avoid an accident. 8) Abnormal vehicle conditions. Hunde and Aged (2015) agreed that it is a risk factor affecting traffic accidents. When driving a vehicle in poor condition, such as with damaged brakes, tyres, or mirrors, if there is an emergency that requires braking, such as someone crossing the road or a light turning red, the vehicle will be unable to respond, such as by failing to brake in time, resulting in a traffic accident. Furthermore, driving in poor road conditions, in unfavourable environmental conditions, or with damaged tyres can result in accidents due to the vehicle's inability to control itself. Furthermore, if a side mirror is damaged, the driver is unable to see the following vehicle and may attempt to overtake the vehicle in front without being able to see the vehicles passing from behind; as a result, accidents may occur. 9) Driving without using personal safety equipment. This is a risk factor affecting traffic accidents (Liu et al., 2008) because the lack of personal safety equipment indicates negligence and careless driving behaviour on the part of the driver, who believes an accident is impossible; thus, there is a higher chance of traffic accidents. In the event of an accident, a person's head may collide with an object such as a vehicle, road, roadside tree, or other roadblock. This would have a direct impact on the brain and could cause serious damage, including disability and death. Personal safety equipment, on the other hand, can help to reduce the severity of an accident. 10) No driving licence. This was also considered by Moradi et al. (2018) as a risk factor influencing traffic accidents. Without a driving license, you have not passed a road traffic exam or received any training. Drivers who do not have a driving licence, they may not have a good understanding of traffic laws. As a result, they are driving illegally and are more likely to cause traffic accidents. 11) Gender. According to Erenler and Gümüş (2019), gender is a risk factor for traffic accidents. Male drivers are more likely to be involved in traffic accidents than female drivers. This is because men are generally less cautious than women when driving. Moreover, male drivers are less likely to be afraid of traffic accidents, whereas female drivers are. Additionally, women drive more cautiously than men. As a result, women face a lower risk of traffic accidents than men.

The development of a simulation system for traffic accidents on major roads in Loei Province, Thailand, by applying a geographic information system and multiple logistic regression with clustering. Regarding simulating traffic accidents with the developed program, several studies have used geographic information systems to analyse traffic accidents (Umam et al., 2021; Audu et al., 2021); some have used geographic information systems with logistic regression statistics to analyse traffic accidents (Audu et al., 2021), and some have used geographic information systems with logistic regression statistics to determine whether a point or area is safe (Rafita et al., 2016). However, none of the studies have investigated roads at the local level for the design of applications to find safe travel routes. The research team simulated the situation of traffic accidents on subdistrict roads by applying the geographic information system and multiple logistic regression with clustering. They applied the standardized coefficient weighted in the simulation using the principle of normalization scored between 0 and 5 and dividing the range of values into 5 ranges to define road risks in 5 groups using 5 colours. This approach actually worked to identify safe routes. However, this study lacks practical application. Therefore, the aforementioned application should be published for use by the general public. The results of such applications can be used to make this application more usable. In addition, since this application is a Windows application, in the future, it should be developed as a mobile application for both iOS and Android systems so that it can easily be used during travel.

This research has limitations in that subdistrict data may not correlate with some cases because traffic accidents did not occur at the highest risk point in the subdistrict. However, in this study, the data of the district's risk points were used as independent variables since the researchers wanted to develop an application to simulate the risk of traffic accidents along the roads in the subdistrict to enable planning to improve and correct the risk points. In addition, the development of the application will enhance caution in travelling when passing through risk points in each subdistrict. However, it may not be possible to use the data at the time of an actual incident to develop an application because 1) there may not be a case for collecting data of risk points or routes in a particular subdistrict. Frequently, when accidents happen to people from outside an area travelling through the area, it causes difficulty in keeping track of the data. This is a significant limitation of this research. People who live in the area mainly farm and use motorcycles; therefore, they do not often travel outside the area of their subdistrict. In addition, the weather and road conditions in the whole subdistrict are similar (based on the survey by the research team). It can be assumed that this method can be used to develop an application for improving the risk points in each subdistrict to improve safety (most of the risk improvements are under the authority of the subdistrict administrative organization). The application also allows users to become more careful and conscious. The research team therefore developed an application to be beneficial for drivers and beneficial for improving the risk points of the local government organization.

4. Conclusion

The results of the multiple logistic regression with clustering analysis revealed that 11 independent variables affect traffic accidents, namely, fog, unclear weather, lack of road lighting, abnormal physical condition, abnormal emotional state, unsafe driving, and illegal driving, performing distracted activities while driving, not using personal safety equipment, abnormal condition of vehicle, and no driving licence. These were combined to predict traffic accidents, and the Pseudo R^2 was 0.5906. When the standardized coefficient of the analysis was used in the traffic accident simulation system, it revealed that it can be applied to geographic information systems at the provincial, district, and subdistrict levels through a traffic accident simulation application. Since the application is a Windows application, to be authentically promoted for general use, it should be developed as a mobile application compatible for convenience and flexibility in use during travel in the future.

The study findings were obtained through multiple logistic regression with clustering of subdistrict-level data, which was applied as the weight in GIS for traffic accident simulation aiming to prevent traffic accidents in each subdistrict. The data analysis examined clusters more appropriately than previous methods. Several data sets, such as road conditions and surroundings, were shared within subdistricts, but previous studies analysed the data as a whole, not as clusters. This method can be generalized for use in other areas. However, this method still needs to be improved since it has only examined observed variables, excluding latent variables. Therefore, in further study, the analysis should apply the multilevel structural equation model and use standardized factor loading to determine the weight in GIS for a more thorough and appropriate traffic accident simulation

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