MATHEMATICAL MODEL FOR PREDICTING THE ROADWAY-CHARACTERISTICS-DEPENDENT TRAVEL TIMES IN RURAL ROADS IN THAILAND

by

Ich Siriprasert
Ph.D. Student, Graduate School, University of the Thai Chamber of Commerce
Vibhavadee-Rangsit Road, Dindaeng, Bangkok, 10400, Thailand
Email: ich_s@drr.go.th

and

Pongtana Vanichkobchinda
Logistics Engineering Department, School of Engineering,
University of the Thai Chamber of Commerce
Vibhavadee-Rangsit Road, Dindaeng, Bangkok, 10400, Thailand
Email: pongtana_van@utcc.ac.th

ABSTRACT

Choosing the fastest path with the aim of saving time or associated costs, has nowadays play a crucial role in both freight and passenger transportation. With the use of traffic simulation models currently available, travel times in urban streets and highways where average speed primarily depends on traffic volume which is apparently very high most of the time, can be obtained. However, in rural roads, especially in Thailand, where congestion rarely occurs due mainly to very low traffic volumes, travel time is rather dependent on roadway characteristics than traffic flow. As a result, the traffic simulation models available can not be used to predict the travel times in rural roads in Thailand effectively. This research therefore identifies roadway characteristics affecting travel times in rural roads, and subsequently develops the mathematical model, based upon road characteristics identified, for predicting the travel times in rural roads in Thailand, by using multiple linear regression. Data on roadway characteristics and travel time, used to calibrate the mathematical model, is collected onsite from 65 rural roads in Thailand and more than 20,000 vehicles, respectively. The research reveals that speeds and travel times for both passenger and freight transport in rural roads in Thailand are influenced by landuse, horizontal and vertical alignment. Number of bridges and access density are found to have effects on travel times and speeds for passenger transport while travel times and speeds for freight transport appear to be affected by lane width of the road.

KEYWORDS

Rural Roads, Mathematical Model, Roadway Characteristics, Multiple Linear Regression

INTRODUCTION

In today’s world, most or almost all people everyday make trips for different personal reasons e.g. work, recreational, social or shopping purposes. In other words, socioeconomics factors e.g. household income, traveler’s age, number of household members, and activity patterns (such as work, education, shopping and community meetings, etc) constitute a major driving force in the travel decision-making process (Mannering et al., 2005). Such an occurrence represents that trip or trip generation has become a basic necessity in our daily lives. For both passenger and freight transportation, people essentially tend to choose the shortest path or fastest path with the purpose of saving travel times and/or associated costs. Owing to its significance and wide range of applications in transportations, a shortest path problem becomes an important issue or task in many networks and transportation related analyses (Zhan and Noon, 1998).

With the application of ongoing traffic simulation models/programs presently available (such as CORSIM; EMME/2; INTEGRATION and TRANSIMS) and the development of mathematical traffic flow models, average speeds and travel times of vehicles in urban streets and highways can be calculated and obtained, and as a result the fastest path can be chosen by travelers. This is mostly computed through the fundamentals of either travel demand & traffic forecasting (four-step model) or traffic flow theory where average speed and travel time primarily depends on travelers’ behavior or traffic volume, respectively (Papacostas and Prevedouros, 2001 and Mannering et al., 2005). Some traffic...
simulation models for rural highways have also been developed in the past few years such as TRARR 4 (by ARRB Transport Research Ltd, Australia), TWOPAS 98 (by Federal Highway Administration (FHWA), USA) and PARAMICS 2001 (by SIAS Ltd, Scotland). These models rely on speed-flow curve or each vehicle on highway is simulated based upon the traffic flow or other traffic movements and all of them still have limitations on road characteristics constraints e.g. gradients for TRARR 4, delay at one-lane bridge for TWOPAS 98 and road width effect for PARAMICS 2001 (Koorey, 2002).

However, these models are not appropriate for rural roads in Thailand (rural minor collectors and local roads considered as class II two-lane rural highways on which motorists do not necessarily expect to travel at high speeds according to Highway Capacity Manual (HCM) 2000) where traffic volume is generally negligible (Annual average daily traffic is less than 1200 Passenger Car Units (PCU). Hence, congestion rarely occurs completely different from what happens in urban highways or arterial roads in which traffic volume is found to be high more often than not. In other words, travel times or average speeds of vehicles traversing rural roads in Thailand is rather dependent upon roadway environment/characteristics (e.g. road width, road pavement and its condition, road curvature, infrastructure constructed along the roadways, etc.) than traffic volume, unlike in highways. These specific characteristics of rural roads are also mentioned in the study of road condition for rural roads in Spain (Gallego, 2008a, b). Disparity in traffic volume between highways and rural roads in Thailand is demonstrated in Figure 1.

As a result, the traffic simulation models and mathematical traffic flow models currently available appear to be not appropriate for predicting average speeds or travel times of vehicles traversing rural roads in Thailand effectively. Consequently, there is a need for research to investigate and identify road characteristics that have effects on speeds of vehicles in rural roads in Thailand, and subsequently establish a mathematical model, based upon these influencing factors identified, for predicting travel times of vehicles traversing rural roads in Thailand. The travel time prediction model is expected to be used for identifying the fastest path for passenger and freight transportation in rural roads in Thailand.

The main objectives of this research study are therefore as follows:

1. To study and identify road characteristics affecting speeds of vehicles traversing rural roads in Thailand
2. To develop a mathematical travel-time prediction model, based upon influencing factors identified, for passenger and freight transportation in rural roads in Thailand.

LITERATURE REVIEW

A number of previous researches have been carried out to either estimate travel time or develop a mathematical for predicting travel times of vehicles. These previous researches can be divided into two main groups: 1) predicting travel times based on relationships between travel times and flow rate, and 2) predicting travel times based on relationships between travel times and speeds.
Predicting travel times based on relationships between travel times and flow rate

Trip assignment (the 4th step in the conventional transportation forecasting model following trip generation, trip distribution, and modal split) basically concerns the selection of routes between origins and destinations in transportation networks based on the total highway traffic demand received from the first three steps. The result of the route choice decision will be traffic flow on specific highway routes between specified origins and destinations used to establish the traffic flow patterns and analyze congestion points. As travelers’ route choice decisions are mainly a function of route travel times determined by traffic flow, relationship between route travel time and route traffic flow is introduced as highway performance function to form the basis of trip assignment theory. For such reason, two relationships have been formalized. The first one is to assume a linear relationship in which travel time increases linearly with flow. Despite the appeal of its simplicity, it is not a realistic representation of the travel time-traffic flow relationship (Mannering et al., 2005). The other approach introduce nonlinear relationship in which route travel time increases more quickly as traffic flow approaches capacity similar to a relationship between traffic speed and flow that is parabolic in nature, with considerable reduction in travel speed occurring as the traffic approaches the roadway’s capacity according to HCM 2000. Both linear and nonlinear travel time-traffic flow relationships are demonstrated in Figure 2.

FIGURE 2
LINEAR AND NONLINEAR TRAVEL TIME-TRAFFIC FLOW RELATIONSHIP

Source: Mannering et al., 2005

In 1964, the Bureau of Public Roads (BPR) in the USA, which later became the FHWA, developed a widely used volume delay function (a specified relationship between the volume of vehicles on a link and the expected amount of time required to traverse that link) used to determine travel time for a vehicle in the trip assignment process. The BPR function is listed below.

\[ t = t_f \left[ 1 + \alpha \left( x_i / C_i \right)^\beta \right] \]

where \( t \) is congested or average travel time for a vehicle on link \( i \), \( t_f \) is free flow travel time on link \( i \), \( C_i \) is capacity of link \( i \), \( x_i \) is flow on link \( i \), and \( \alpha \) and \( \beta \) are calibration constant which is often set at 0.15 and 4, respectively.

In an attempt to overcome the BPR functions’ inherent drawbacks (e.g. assumptions of v/c), Spiess (1990) developed a new class of function namely conical volume delay function which constitute a viable alternative to the BPR type function. The conical volume delay function is defined as:
\[ t(v) = t_0 \left[ 2 - \beta - \alpha \left( 1 - \frac{v}{c} \right) + \sqrt{\alpha^2 + \left( 1 - \frac{v}{c} \right)^2 + \beta^2} \right] \]  \hspace{1cm} (2)

where \( t(v) \) is average travel time, \( t_0 \) is free flow travel time, \( c \) is road capacity, \( v \) is road traffic flow, \( \alpha \) is any number larger than 1 and \( \beta \) is given as:

\[ \beta = \frac{2\alpha - 1}{\alpha - 2} \]  \hspace{1cm} (3)

Several previous researches have been done to estimate travel time for a vehicle by using neural networks. Rilett and Park (1999) utilised spectral basis neural networks (SNN) to predict multiple-periods freeway corridor travel times based on traffic flow data collected from US 290 in Houston, Texas in the USA. The results of the study revealed that the mean absolute percent error for predicting travel time using SNN ranges from 5.9 percent to 15.3 percent from 5 minutes to 25 minutes. It was also found that the higher the time period, the higher errors will be when using SNN to predict the travel time on freeway.

Ishak and Alecsandru (2003) applied multiple topologies of dynamic neural network to optimize the short-term travel time prediction. The research also tested and compared four different types of neural network architectures under different settings and traffic conditions. The four different neural networks are 1) Multi-Layer Perceptron network 2) Modular network 3) Hybrid Principal Component Analysis network and 4) Co-Active Neuro-Fuzzy Inference System (CANFIS). The results show that CANFIS network was the optimal topology.

Nevertheless, theses previous researches or mathematical functions, because they tend to predict the travel time based primarily upon traffic volume and/or capacity of roads, appears to be not suitable for predicting travel time in rural roads in Thailand in which traffic volume apparently has inconsiderable or no influence on traffic movement, and thus average speeds/travel times of vehicles.

**Predicting travel times based on relationships between travel times and speed**

This group of previous work basically develops mathematical models for predicting speeds based on a variety of factors influencing vehicle speeds, and subsequently travel times can be computed through the relationships between travel time, speed and distant traveled as written below (Cutnell and Johnson, 2001).

\[ \frac{v}{a v} = \frac{s}{t} \]  \hspace{1cm} (4)

where \( v_{av} \) is average speed when traveling from origin to destination, \( S \) is distance traveled from origin to destination and \( t \) is travel time used to move from origin to destination.

A number of earlier studies have indicated that there were many factors influencing the speed of a vehicle on a road. Agreements and disputes can however be found in the results of these previous studies as to whether which factors impact on drivers’ speed choices. Wahlgren (1967) summarized the general groups of factors that influence speeds into six main categories: road conditions, driver characteristics, vehicle characteristics, traffic conditions, road environment and other factors. However, some recent work, such as Kanellaidis (1995), Giles (2004) and SWOV (2008), came to the same conclusion that drivers’ speed choice is a complex process which involves an interaction between three major factors: driver characteristics, vehicle characteristics and road characteristics and environment as shown in Figure 3.
Wortman (1965) investigated variables present on 4-lane rural highways which represent the driver, vehicle, roadway, traffic conditions and environment characteristics, with the hypothesis that a variation in the types and levels of travel features of the roadway will cause a variation in the vehicle speeds. 38 variables were measured at different 83 study sites in Illinois, USA and were used in conjunction with multiple linear regression to develop a speed prediction model which will be used to establish speed zones based on safe and reasonable vehicular speeds. This study revealed that percentage of out-of-state passenger car, sight distance, posted speed limit and number of roadside establishments had effects on vehicular speeds.

Crisman (2005) examined the impacts of geometric roadway characteristics on vehicle speeds in order to develop speed prediction models used to evaluate the design consistency of existing and new roads which is related to road accident rates. Data on road characteristics and vehicle speed was collected at 50 sites on four two-lane rural highways in Italy. The operating speed prediction model was developed with the use of multiple linear regression together with geometric roadway characteristics (curve radius and road curvature), and these geometric roadway characteristics were found to have influence on operating speeds of vehicles. The statistics analysis in this research also represented the heavy dependence of the operating speeds of vehicles on the geometric characteristics of the road section. The developed model can be used to check the road design consistency that identifies unacceptable speed change along the road in attempt to promote overall traffic safety.

Abdul-Mawjoud and Sofia (2008) conducted research with the aim of developing 85th percentile speed prediction equations deriving from data on spot speeds of more than 7,000 passenger cars and road characteristics collected at 28 two-lane rural highways in northern Iraq. The speed prediction model was developed by using multiple linear regression and was validated using observed values from another 20 road sites. The research found that only four geometric road variables: superelevation, deflection angle, radius of curve and 85th percentile approach speed, appeared to have effects on vehicle speeds.

These previous work unfortunately did not include or consider some factors, particularly bridges along the roadway and pavement type, and they were carried out for urban or rural highways. With respect to the rural roads in Thailand, bridges are considered as important part of the roads due to their significant numbers along the rural roads. The function of rural roads in Thailand is, as mentioned before, designed to be minor collector or local roads providing access to remote/rural villages or lands for agricultural or forestry activities, unlike rural highways in Europe or Western countries where the function of rural highways is connecting the cities which resembles highways in Thailand (Bennett, 1994 and Gallego, 2008a, b). Hence, concrete pavement is a major part of rural road networks in some provinces in Thailand, e.g. Samut Prakan and Samut Sakorn, and high access/junction density appear along rural roads in Thailand whilst rigid pavement, bridges and junctions rarely appear along rural highways in New Zealand and other countries.

The design of rural roads in Thailand is also far below or not up to the general standards of highway design, for example, very narrow bridge and road, poorly-designed-gradient bridges, no super elevation, no posted speed limit, very low designed speeds and many consecutive sharp curves available due mainly to unavailability of land and limited road construction budget allocated annually. This once more reflects that the road characteristics and design criteria elements of rural roads in Thailand are apparently different from those of rural highways studied in previous researches e.g. Canada by Yagar (1984), New Zealand by Bennett (1994) and Italy by Crisman (2005). The difference of geometric roadway characteristics between rural highways in European and Western countries and rural roads in Thailand can be seen clearly in Figure 4.
RESEARCH METHODOLOGY

There are four consecutive steps in performing this research, as listed below.

Identifications of road characteristics/environment factors

Literature review was carried out in order to ascertain which factors have already been identified to have influence or no influence on drivers’ speed choices. Influencing factors were included in the research with the rest being ruled out. The literature review highlighted that vehicle speed derived from the interaction of road, driver and vehicle characteristics. As stated above, the road characteristics tend to take over the speed picture in rural roads in Thailand, and it not only appears to be costly but also requires human resources to a large extent and close cooperation from the police together with other relevant organizations, making it a complex process, to collect data on driver and vehicle characteristics while conducting roadside survey to observe vehicle speeds (Kanellaidis, 1995, Quimby et al., 1999 and Slinn et al., 2005). Only road environment/characteristics were therefore investigated and chosen as factors that are likely to have effects on vehicle speeds in rural roads in Thailand.

With low design criteria and specific roadway characteristics of rural roads in Thailand, some road characteristics can be disregarded from the research, for example, posted speed limit, number of lane and median type, with the remaining characteristics being observed in experimental field study. The roadway characteristics investigated in the research is listed in Table 1.

<table>
<thead>
<tr>
<th>Category</th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road Characteristics</td>
<td>Road width, lane width, shoulder width, road curvature, length of curve, degree of curve, characteristics and number of bridges along roadway, number of access and intersection along roadway, International Roughness Index (IRI), pavement type,</td>
</tr>
<tr>
<td>Road Environment</td>
<td>Landuse</td>
</tr>
</tbody>
</table>

Experimental set up

Roadside survey was undertaken to not only collect data on roadway characteristics and environment, but also observe speeds of vehicle on rural roads in Thailand. Some information on road characteristics e.g. IRI was obtained from road inventory database of the Department of Rural Roads whereas others was collected onsite, for instance, road
curvature measured by using a compass. License plate observation method was used in combination with digital timers, as demonstrated in Figure 5, to collect data on travel times of vehicles traversing homogeneous road sections, ranging from 0.5 to 3 kilometers length, selected from rural roads in Thailand so that journey speeds of these vehicles can be calculated later. Three main types of vehicles were collected at this stage: 1) passenger cars including vans, buses and pick up cars, 2) motorcycles and 3) trucks including six-wheel trucks, ten-wheel trucks, trailers and semi-trailers. Data on roadway characteristics and environment was collected at different 65 road sites while travel times of more than 20,000 vehicles were observed in the research.

![FIGURE 5](LICENSE PLATE OBSERVATION METHOD)

Source: Modified from Turner et al., (1998)

**Development of speed prediction model**

In order to develop a speed prediction model, journey speeds of vehicles were computed from travel time collected onsite using the following equation (Slinn et al., 2005). Travel times of passenger cars and motorcycles were combined to compute journey speeds for passenger transportation while the space mean speeds for freight transportation were derived from travel times of trucks.

\[
V = \frac{l}{\sum_{i=1}^{n} t_i}
\]

where \(V\) is space mean speed or journey speed, \(l\) is length of road section traveled, \(t_i\) is travel time of the \(i^{th}\) vehicle and \(n\) is number of vehicles observed.

Software PASW Statistics 18 was used to develop a mathematical relationship between journey speeds computed, and road characteristics and environment factors listed in Table 1. Some factors were transformed into individual indices e.g. road curvature converted into curvature change rate (CCR), before entering the software. Multiple linear regression was used in conjunction with the factors & indices, and journey speeds of passenger cars, motorcycles and trucks to develop a mathematical model for predicting speeds for passenger and freight transportation.

**Development of travel time prediction model**

The mathematical model for predicting roadway-characteristics-dependent travel times in rural roads in Thailand was developed based upon the obtained speed prediction model through the relationships between average speed, travel time and distance traveled as shown in Equation (4). In other words, the travel time prediction model was developed by dividing traveled distance or trip length variable with the mathematical speed prediction model.
RESULTS AND DISCUSSION

With the use of the software PASW Statistics 18 and multiple linear regression algorithm, the speed prediction models for passenger and freight transportation in rural roads in Thailand were developed as can be seen below.

\[ V_{pg} = 17.767 - 0.303 \sqrt{ccr} - 1.501g - 3.237r - 1.096bg - 0.018ai - 0.177ad \] .......(6)

\[ V_{fr} = 11.865 - 0.008ccr + 3.276rf + 2.527id - 0.014ig \] .................................(7)

where \( V_{pg} \) is average speed for passenger transport, \( V_{fr} \) is average speed for freight transport, \( ccr \) is curvature change rate, \( g \) is garden (1 if landuse alongside roadway is garden; otherwise 0), \( r \) is resident (1 if landuse alongside roadway is resident; otherwise 0), \( bg \) is number of the bridges along roadway, with average grade of between 8% and 12%, \( ai \) is average upgrade and downgrade length per road length, \( ad \) is access density (number of accesses and intersections per road length), \( rf \) is rice field (1 if landuse alongside roadway is rice field; otherwise 0), \( id \) is lane width larger than 3 meters, and \( ig \) is upgrade and downgrade length per road length.

These speed prediction models represent that average speed for passenger transportation in rural roads in Thailand is mainly influenced by roadway environment (landuse,) and roadway characteristics (number of bridges along roadway, road curvature, access density and average upgrade and downgrade length per road length. On the other hand, only road curvature, landuse, upgrade and downgrade length per road length and lane width were found to have effects on speeds for freight transport. It indicates that horizontal and vertical alignment tend to pose threat to speeds for both passenger and freight transport in rural roads in Thailand while the dependence of vehicle speeds on landuse is subject to the type of landuse alongside the roadway. In other words, passenger cars moving through garden and residential area tend to travel slower whereas rice field alongside the roadway appears to add mobility to freight transport. The explanation could be that garden landuse decreases drivers’ visibility and it is expected a number of pedestrians crossing roads in residential areas, thus leading to slower speed choices for drivers. However, drivers’ visibility seems not to deteriorate when landuse alongside the road is rice field.

Mobility of passenger transport tends to be affected by number of accesses and intersections along the road whilst the width of lane appears to have influence on speeds for freight transport. The wider the lane, the higher the speeds of trucks driven, but the higher the access density, the lower, the speed chosen by drivers of passenger cars. The larger size of the trucks, semi-trailers and trailers could justify why their speeds are found to be dependent on lane width of the road. As the passenger cars tend to move faster than trucks or trailers, it is likely that the mobility of the passenger transport could be much more influenced by accesses and intersections along the roadway or vehicles weaving at these points than those of freight transport. The statistics for the speed prediction models for passenger and freight transport are listed in Table 2, 3 and 4.

### Table 2

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R²</th>
<th>Adjusted R²</th>
<th>Standard Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger</td>
<td>0.919</td>
<td>0.844</td>
<td>0.815</td>
<td>1.1168810</td>
</tr>
<tr>
<td>Freight</td>
<td>0.826</td>
<td>0.682</td>
<td>0.638</td>
<td>2.0267124</td>
</tr>
</tbody>
</table>

From Table 2, the models are examined by the coefficient of determination (\( R^2 = 0.844 \) for passenger and \( R^2 = 0.682 \) for freight) which implies that the passenger model has about 84.4% influences on the mobility of the passenger transport, and the speed data variation for freight transport of 68.2% is attributed to the variables in freight model. This highlights that there should be other influencing factors or variables that have not been included in the models. These factors could be other road characteristics/environment variables or come from driver and vehicle characteristics.

The analysis of variance (ANOVA) was used to statistically test the null-hypothesis of the models that whether no independent variable or factor in the model (road characteristics and road environment) is correlated with the dependent variables \( V_{pg} \) and \( V_{fr} \) as shown in Table 3. The p-values of 0.000 for passenger and freight models implies that the null hypothesis is rejected or there is at least one independent variables, which is in the models is significantly correlated with the dependent variables.
TABLE 3

ANOVA SUMMARY FOR PASSENGER AND FREIGHT MODELS

<table>
<thead>
<tr>
<th>Model</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger</td>
<td>Regression</td>
<td>216.418</td>
<td>6</td>
<td>36.070</td>
<td>28.915</td>
</tr>
<tr>
<td></td>
<td>Residual</td>
<td>39.918</td>
<td>32</td>
<td>1.247</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>256.335</td>
<td>38</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freight</td>
<td>Regression</td>
<td>255.680</td>
<td>4</td>
<td>63.920</td>
<td>15.562</td>
</tr>
<tr>
<td></td>
<td>Residual</td>
<td>119.119</td>
<td>29</td>
<td>4.108</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>374.799</td>
<td>33</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

T-Test was also used to statistically check the relationship between dependent variable and each independent variable in the models. The p-value of less than 0.05 for each independent variable in the models, as listed in Table 4, indicates that each factor or dependent variable in the model has statistically significant correlation with dependent variable.

TABLE 4

VARIABLE COEFFICIENTS SUMMARY FOR PASSENGER AND FREIGHT MODELS

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardised Coefficients</th>
<th>Standardised Coefficients</th>
<th>T</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B Standard Error Beta</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passenger</td>
<td>Constant -17.767 0.524 - 33.938 0.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ccr -0.303 0.032 -0.761 -9.449 0.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>g -1.501 0.428 -0.292 -3.508 0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>r -3.237 0.728 -0.336 -4.446 0.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>bg -1.096 0.281 -0.309 -3.895 0.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ai -0.018 0.006 -0.232 -2.985 0.005</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ad -0.177 0.066 -0.205 -2.697 0.011</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freight</td>
<td>Constant 11.865 0.808 - 14.681 0.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ccr -0.008 0.002 -0.396 -3.262 0.003</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>rf 3.276 0.999 0.399 3.279 0.003</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>id 2.527 0.958 0.307 2.638 0.013</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ig -0.014 0.005 -0.294 -2.606 0.014</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The travel time prediction models for passenger and freight transportation were derived from the developed speed prediction models above using the relationship between average speed, travel time and trip length or distance traveled as shown in Equation (4). These travel time prediction models are written below. The developed travel time prediction models are expected to be used for route selection in rural roads in Thailand by determining the fastest path based on travel time calculated from the models.

\[
T_{pg} = \frac{S}{17.767 - 0.303 \sqrt{ccr} - 1.501 g - 3.237 r - 1.096 bg - 0.018 ai - 0.177 ad} \quad \text{(8)}
\]

\[
T_{fr} = \frac{S}{11.865 - 0.008 ccr + 3.276 rf + 2.527 id - 0.014 ig} \quad \text{.................................(9)}
\]

where \(T_{pg}\) is travel time for passenger transport, \(T_{fr}\) is travel time for freight transport and \(S\) is distance traveled or trip length.
CONCLUDING REMARKS

In summary, the travel time prediction models developed based upon the speed model in conjunction with the relationship between average speed, travel time and distance traveled indicate that speeds and travel times of vehicles in rural roads in Thailand appear to be mainly influenced by roadway characteristics and environment. Horizontal & vertical alignment and landuse are found to have effects on mobility of both passenger and freight transport in rural roads in Thailand. Speed choices of passenger cars’ drivers tend to be affected by the number of access and intersections along the road whereas the speeds and travel times of trucks are apparently dependent on lane width of the road. Nevertheless, further investigation and studies are required to identify and include more factors e.g. driver characteristics and vehicle characteristics, in the speed and travel time prediction models to improve the goodness of fit of the models for their practical use in the future.

FUTURE RESEARCH

1. Even though the speed and travel time prediction models developed in the research are found to be statistically significant, these models were built on the observations of 65 road sites only with no validation being carried out yet. Hence, it is necessary to collect data on more road sites for validating these models prior to their practical application in the future.

2. R² for the speed prediction models for passenger and freight transport indicates that the models partially or significantly fit the data. This means that there are still other factors or variables that are not included in the developed models, having effects on vehicle speeds in rural roads in Thailand. Hence, future research should be carried out to develop the speed and travel time prediction models based upon more factors or variables such as driver characteristics, vehicle characteristics and other road characteristics/environment that are not included in the models developed in the research.

3. Although most of rural roads in Thailand are low volume roads as their functions stand, some rural roads do have medium or high traffic volumes in reality because they pass through tourist destinations or important areas/community/villages. Both the speed and travel time prediction models are developed on the basis that rural roads have such low volume that speed choices of drivers tend to be influenced by roadway characteristics and environment rather than traffic volume. As a result, the models developed in the research are apparently not to be appropriate for all rural roads in Thailand. Consequently, further research should be conducted to develop speed and travel time prediction models for rural medium and high volume roads in Thailand so that route selection or fastest path determination can be done accurately and effectively for both passenger and freight transport in all rural roads in Thailand.

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