Mathematical Models for Predicting Roadway-Characteristics-and-Level-of-Service-Dependent Travel Times on Rural Roads in Thailand

Ich Siriprasert and Pongtana Vanichkobchinda, *Member, IACSIT*

***Abstract*—With the use of traffic simulation models, travel times on urban streets and highways where average speed primarily depends on traffic volume which is apparently high most of the time, can be obtained. However, on rural roads, especially in Thailand, where congestion rarely occurs due mainly to very low traffic volume, travel time is rather dependent on roadway characteristics and environment than traffic flow. As a result, the traffic simulation models currently available cannot be used to predict the travel times on rural roads in Thailand effectively. This research therefore identifies roadway characteristics and environment affecting speeds of vehicles on rural roads, and subsequently develops the mathematical models based upon road characteristics and environment identified, for predicting travel times of passenger and freight transport on rural roads in Thailand, by using multiple linear regression. Data on roadway characteristics and travel times, used to calibrate the mathematical models, were collected onsite from 66 rural roads in Thailand and more than 20,000 vehicles, respectively. The research reveals that speeds and travel times for both passenger and freight transportation on rural roads in Thailand appear to be mainly influenced by adjacent land use, presence of horizontal curvature and bridges along the road. However, the effects of these factors are found to vary according to level of service for the roads.**

***Index Terms*—Mathematical models, level of service, roadway characteristics, rural roads.**

I. 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, such as household income, traveler's age, number of household members, and activity pattern constitute a major driving force in the travel decision-making process. Such an occurrence represents that trip or trip generation has become a basic necessity in our daily lives [1]. For both passenger and freight transportation, people tend to choose the shortest or fastest path with the purpose of saving 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 [2].

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 on urban streets and highways can be calculated, and as a result the fastest path can be chosen by travelers. This is mostly computed through the fundamentals of either travel demand and traffic forecasting (i.e. four step model) or traffic flow theory where average speed and travel time primarily depends on travels' behavior or traffic volume, respectively [3].

However, these models appear to be not appropriate for two-lane rural roads in Thailand (rural minor collectors or local roads considered as class II two-lane highways on which motorist 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 1100 Passenger Car Units (PCU).). Hence, congestion rarely occurs different from what happens on urban highways or arterial roads where traffic volume is usually found to be high. In other words, travel times or average speeds of vehicles traversing rural roads in Thailand is rather dependent on roadway characteristics (e.g. road curvature, road width, etc.) and environment than traffic volumes, unlike on highways.

As a result, the traffic simulation models and mathematical 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 roadway characteristics and environment affecting speeds of vehicles on rural roads in Thailand, and subsequently establish mathematical models, based on the influencing factors identified, for predicting travel times of vehicles traversing rural roads in Thailand. The travel time prediction models are expected to be used for not only route selection for passenger and freight transport on rural roads in Thailand by identifying the fastest path, but also for rural road improvement to provide better traffic operational conditions.

II. Literature Review

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

For the first group of previous researches, several models have been developed to determine travel time for a vehicle in

Manuscript received February 13, 2012; revised February 24, 2012.

Authors are with Department of Logistics Engineering, University of the Thai Chamber and Commerce, Vibhavadee-Rangsit Road, Dindaeng, Bangkok, Thailand (email: deadload@hotmail; ich_s@drr.go.th; pongtana_van@utcc.ac.th.)

the trip assignment process, for example, the volume delay function by the Bureau of Public Roads (BPR) in the USA [4], which later became Federal Highway Administration (FHWA), and the conical volume delay function as in [5]. Neural networks were also used in previous work to estimate travel time for a vehicle. Reference [6] applied multiple topologies of dynamic neural networks to optimize the short-term travel time prediction. Nonetheless, these previous researches, because they tend to predict travel time based primarily on traffic volume, appear to be not suitable for predicting travel times in rural roads in Thailand where traffic volume apparently has inconsiderable influence on average speeds and travel times of vehicles.

The other group of previous work basically developed mathematical models for predicting speeds based on a variety of factors influencing vehicle speeds, and then travel times can be computed through the relationships between travel time, average speed and distance traveled as shown below.

$$S = V_{av}\, t \quad (1)$$

where V_{av} is average speed, S is distance traveled and t is time used to travel from origin to destination as in [7].

Agreement and dispute can be found in the results of the previous studies as to whether which factors have impacts on drivers' speed choices. Some recent work, such as [8] and [9], came to the similar conclusion that drivers speed choice is a complex process which involves an interaction between three major factors: driver characteristics, vehicle characteristics, and roadway characteristics and environment.

The previous mathematical models developed for predicting speeds as in [10] and [11], unfortunately did not include or consider some factors, particularly bridges along the roadway and pavement type, and these researches were conducted for urban or rural highways in Europe or Western countries. As for rural roads in Thailand, bridges are considered as important part of rural roads due to their significant numbers along the roads. The function of rural roads in Thailand is, as mentioned before, designed to serve as communication routes between communities providing access to rural villages or lands for agricultural activities, unlike rural highways in Europe and Western countries where the function of rural highways is connecting cities, which resembles highways in Thailand as in [12] and [13]. Hence, concrete pavement is a major part of rural networks in some provinces in Thailand and high access density appears along rural roads in Thailand whilst rigid pavement, bridges and junctions rarely appear along rural highways in Europe and Western countries.

The design of rural roads in Thailand is also not up to the general standards of highway design. For example, no posted speed limit, no super-elevation, no median and many consecutive sharp curves available due to unavailability of land and limited road construction budget allocated annually. This once more reflects that road characteristics and design criteria elements of rural roads in Thailand are apparently different from those of rural highways studied in previous researches.

More importantly, the previous work also developed the general models only, but in fact one general model should not represent all highways as traffic operational conditions for highways basically vary according to the concept of level of service (LOS). Therefore, this research will be built on the gaps of these previous researches by developing mathematical models, based on roadway characteristics and environment, for predicting travel time on rural roads with different level of service, through the relationships between travel time, average speed and distance traveled.

III. Research Methodology

A. Identification of Influencing 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 remaining factors being ruled out. The literature review highlighted that vehicle speed was derived from the interaction of road, driver and vehicle characteristics. As stated above, roadway characteristics and environment tend to dominate the speed picture on 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 gather data on driver and vehicle characteristics while collecting travel times of vehicles as mentioned in [8], [14] and [15]. Only roadway characteristics and environment were therefore investigated and chosen as factors that are likely to have influence on vehicle speeds on rural roads in Thailand.

With low design criteria and specific characteristics of rural roads in Thailand, some roadway 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 and environment investigated in the research is listed in Table I.

TABLE I: Road Characteristics and Environment

Category	Factors
Characteristics	Road width, lane width, shoulder width, road curvature, length of curve, degree of curve, radius of curve, bridges along roadway, number of access and intersection, pavement type, International Roughness Index (IRI)
Environment	Type of adjacent land use

B. Experimental Setup and Data Collection

Roadside survey was undertaken to not only collect data on roadway characteristics and environment, but also observe travel times of vehicles traversing rural roads in Thailand. Some information on roadway characteristics e.g. IRI was obtained from road inventory data base of the Department of Rural Roads whereas other data were collected onsite, for instance, road curvature measured by using a compass. License plate observation method was used in combination with digital timers to collect data on travel times of vehicles traversing homogeneous road sections, ranging from 0.5 to 3.0 kilometers length, selected from rural roads in Thailand so that journey speeds of these vehicles can be calculated later. Two main types of vehicles were collected at this stage:

passenger cars including vans, buses and pickup cars; and trucks including six-wheel trucks, ten-wheel trucks, trailers and semi-trailers. Data on roadway characteristics and environment were collected at different 66 road sites while travel times of more than 20,000 vehicles were observed in roadside survey.

C. Calculation of Level of Service

In order to develop mathematical models for different LOS, LOS for all rural roads in Thailand were determined by calculating percent time spent following (PTSF) according to HCM 2000 using necessary information e.g. traffic volume, peak-hour factor (PHF) from road inventory database of the Department of Rural Roads. The calculation revealed that rural roads in Thailand are fallen into four LOS categories (A, B, C and D); most of which were classified as LOS A as shown in Table II. Because of this, mathematical models for LOS A, B and C&D were developed in the research later.

TABLE II: LEVEL OF SERVICE FOR RURAL ROADS IN THAILAND

Number of Rural Roads in Thailand (%)			
LOS A	LOS B	LOS C	LOS D
85.78	10.07	3.19	0.95

D. Development of Speed and Travel Time Prediction Models

In order to develop speed prediction models, journey speeds of passenger cars and trucks were computed from travel times collected onsite. Travel times of passenger cars and trucks were used to calculate journey speeds of passenger and freight transportation, respectively. Software PASW Statistics 18 (SPSS 18) was used to develop a mathematical relationship between journey speeds computed, and roadway characteristics and environment factors listed in Table I, based on multiple linear regression algorithm listed below.

$$Y_i = \beta_0 + \beta_1 X_i \quad + \beta_2 X_{i2} + \ldots\ldots + e_i,\ i = 1, \ldots, n \quad (2)$$

Where X_{i1} and X_{i2} are predictor variables, Y_i is a response variable, e_i is random error ,and β_0, β_1 and β_2 are unknown regression parameters as in [16].

Some factors were transformed into individual indices in order to meet the linearity assumption of the regression model, e.g. road curvature converted into curvature change rate, before entering the software. Stepwise regression was used in conjunction with the factors and indices, and journey speeds of passenger cars and trucks to develop mathematical models for predicting speeds of passenger and freight transportation on rural roads with LOS A, B and C&D.

The mathematical models for predicting travel times on rural roads in Thailand, based on roadway characteristics and environment, and LOS, was then developed through the relationships between average speed, travel time and distance traveled as in (1).

IV. RESULTS AND DISCUSSION

With the use of the software PASW Statistics 18 and stepwise regression, the speed prediction equations for passenger and freight transportation on rural roads with different LOS were developed as listed below.

$$V_{p\,A} = 18.509 - 0.009C - 4.447G - 0.011B - 0.011LL \quad (3)$$

$$V_{p\,B} = 14.921 - 0.012C - 0.007B \quad (4)$$

$$V_{p\,C\&D} = 14.908 - 0.010C - 0.006L + 0.541RW \quad (5)$$

$$V_{fr\,A} = 7.206 - 0.007C - 3.652G - 0.012B + 1.002RW \quad (6)$$

$$V_{fr\,B} = 12.570 - 0.010C - 0.012B \quad (7)$$

$$V_{fr\,C\&D} = 17.841 - 0.012C - 0.322R - 0.004L - 0.008B \quad (8)$$

where $V_{p\,A}$ is average speed for passenger transport on rural roads with level of service A in meter per second, $V_{fr\,A}$ is average speed for freight transport on rural roads with level of service A in meter per second, C is horizontal curvature in degree per kilometer, G is garden (1 if land use alongside roadway is classified as garden or forest, otherwise 0), B is bridge length along the road in meter per kilometer, L is length of curve in meter per kilometer, LL is average length of curve in meter per kilometer, RW is road width in meter and R is road roughness in meter per kilometer.

The speed prediction models developed above represent that average speeds of both passenger and freight transport are mainly influenced by roadway environment (adjacent land use), and roadway characteristics (presence of horizontal curvature and length of bridges along the road). However, the disparity between passenger and freight models lie in the variation of the effects of these factors and other factors on average speeds in different LOS models.

As for passenger models, average speed is found to be affected by land use in LOS A model only while horizontal curvature appears to slow down the movement of passenger cars in all LOS models. The negative influence of vertical alignment or length of bridges along the road on average speed in LOS A and B models is found to disappear in LOS C&D model, with road width being seen to add mobility to passenger transport instead. An explanation could be that when drivers are virtually unaffected by the presence of others in the traffic stream (free-flow condition or LOS A), presence of horizontal curvature and length of bridges along the road pose threat to mobility of passenger cars and land use alongside the road appears to have an impact on speed choices depending on the type of land use. Passenger cars moving through garden or forest tend to travel slower because it is likely that garden or forest decreases drivers' visibility, thus leading to slower speed choices for drivers. However, when freedom to select speeds and to maneuver within the traffic stream declines with increasing flow, the influence of land use and bridges on speed choices becomes minimal while the effects of horizontal curvature still remains. Under this condition where careful attention is required for driving, wider road width give more freedom for drivers to maneuver, thus allowing higher speed choices available.

Although the influence of horizontal curvature and land use on speeds of freight transport are similar to what is found in passenger transport, the effects of bridges along the road and road width on speed choices of freight transport are different. Presence of bridges along the road is found to pose threat to speeds of freight transport in all LOS models. The effect of road width on speed of freight transport is apparent in LOS A model only while road roughness appears as an influencing factor in just LOS C model. It indicates that under free-flow condition, presence of horizontal curvature and bridges along the road appear to slow down trucks. Adjacent land use is also found to have an impact on speed choices depending on the type of land use, like passenger transport. With large size of trucks, the wider road width increases comfort and convenience for drivers to maneuver, thus possibly allowing higher speed choices chosen or vice versa.

However, when the freedom to maneuver becomes more restricted and drivers experience reductions in physical and psychological comfort as a result of increasing flow, the influence of land use and road width on truck speeds diminish or become negligible while the effects of horizontal curvature and bridges along the road remain evident. Under this condition, road roughness is found as another factor affecting speeds of trucks. An explanation could be that more careful attention is required for driving trucks on rough roads in order to avoid damage to goods or other vehicles in the traffic stream. Hence, the higher the IRI, the lower the speed choice is selected for freight transport or vice versa.

The speed prediction models developed above are examined by the coefficients of determination (R^2) as illustrated in Table III. From Table III, the R^2 for passenger and freight transport models range from 0.627 to 0.970 indicating that at least more than 62.7% of the speed data variation for passenger and freight transport on rural roads with LOS A, B and C&D are attributed to the variables in the models; or in other words, the models developed considerably fit the data and less than 37.3% of total variance cannot be explained by the models. This however implies that there should be other factors or variables affecting vehicle speeds, which have not been included in the models yet. These factors could be other roadway characteristics and environment or driver and vehicle characteristics.

TABLE III: SUMMARY OF PASSENGER AND FREIGHT MODELS

Model		R	R^2	Adjusted R^2
Passenger	LOS A	0.917	0.842	0.804
	LOS B	0.792	0.627	0.574
	LOS C&D	0.985	0.970	0.957
Freight	LOS A	0.904	0.818	0.779
	LOS B	0.822	0.676	0.626
	LOS C&D	0.977	0.955	0.930

The analysis of variance (ANOVA) was used to statistically test the null-hypothesis of all the developed models that whether no independent variable or factor (roadway characteristics and environment) in the models is correlated with the dependent variables (average speeds of passenger and freight transport) as shown in Table IV.

TABLE IV: ANOVA SUMMARY FOR PASSENGER AND FREIGHT MODELS

Model		F-test	Significance
Passenger	LOS A	22.575	0.000
	LOS B	11.763	0.001
	LOS C&D	74.564	0.000
Freight	LOS A	21.299	0.000
	LOS B	13.537	0.001
	LOS C&D	37.391	0.000

The p-values of 0.000 and 0.001 for the models imply that the null hypothesis is 99% statistically rejected or in each model at least one independent variable is significantly correlated with the dependent variable.

T-test was also used to statistically check the relationship between dependent variable and each independent variable in the models, as summarized in Table V.

TABLE V: VARIABLE COEFFIENTS FOR PASSENGER AND FREIGHT MODELS

Variable	Significance for models					
	Passenger model			Freight model		
	LOS A	LOS B	LOS C&D	LOS A	LOS B	LOS C&D
Constant	0.000	0.000	0.000	0.025	0.000	0.000
C	0.007	0.000	0.000	0.038	0.002	0.000
G	0.000	-	-	0.000	-	-
B	0.004	0.017	-	0.002	0.000	0.028
L	-	-	0.000	-	-	0.007
LL	0.005	-	-	-	-	-
RW	-	-	0.003	0.020	-	-
R	-	-	-	-	-	0.008

The p-values of less than 0.05 for all independent variables in the models indicate that each factor or independent variable in all the models has 95% statistically significant correlation with dependent variable; or each factor in the models statistically has influence on average speeds of passenger transport and/or freight transport in rural roads in Thailand.

The travel time prediction models for passenger and freight transport were derived from the developed speed prediction models using the relationships between average speeds, travel time and distance in (1), as listed below.

$$T_{pA} = \frac{S}{18.509 - 0.009C - 4.447G - 0.011B - 0.011LL} \quad (9)$$

$$T_{pB} = \frac{S}{14.921 - 0.012C - 0.007B} \quad (10)$$

$$T_{p\,C\&D} = \frac{S}{14.908 - 0.010C - 0.006L + 0.541RW} \quad (11)$$

$$T_{fr\,A} = \frac{S}{7.206 - 0.007C - 3.652G - 0.012B + 1.002RW} \quad (12)$$

$$T_{fr\,B} = \frac{S}{12.570 - 0.010C - 0.012B} \quad (13)$$

$$T_{fr\,C\&D} = \frac{S}{17.841 - 0.012C - 0.322R - 0.004L - 0.008B} \quad (14)$$

Where T_{pA} is travel time for passenger transport on rural roads with level of service A in second, $T_{fr\,A}$ is travel time for freight transport on rural roads with level of service A in second and S is distance traveled in meter.

These travel time prediction models are expected to be used for route selection for passenger and freight transport on rural roads in Thailand by determining the fastest path based on travel times calculated from the models. Additional application of these models can be in the improvement of rural road characteristics to provide better traffic operational conditions for passenger and freight transport by comparing average speeds or travel times of vehicles traversing existing roads with enhanced ones.

V. Conclusion

In summary, the travel time prediction models developed based on the speed models in conjunction with the relationships between travel time, speed and distance traveled indicate that speeds and travel times of both passenger and freight transport on rural roads in Thailand are found to be primarily influenced by roadway environment (type of adjacent land use), roadway characteristics (presence of horizontal curvature and bridges along the road). However, the difference between freight and passenger models appears to be the variation of the effects of these factors and presence of other factors (e.g. road width and IRI) on rural roads with different LOS. With distinct effects and presence of factors in different LOS models, speed and travel time prediction models for specific LOS roads seemingly appear to be more appropriate or accurate than general models developed in previous work. However, further investigation and studies are required to identify and include more factors e.g. other roadway characteristics and environment, 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.

References

[1] F. L. Mannering,, W. P. Kilareski, W. P. and S. S. Washburn, *Principles of highway engineering and traffic analysis*, 3rd ed. Wiley & Sons, Inc., New Jersey, 2005, pp. 270-276.

[2] F. B. Zhan and C. E. Noon, "Shortest path algorithms: an evaluation using real road networks", *Transportation Science*, vol. 32, No. 1, pp. 65-73, 1998.

[3] C. S. Papacostas and P. D. Prevedouros, *Transportation engineering and planning*, 3rd ed. Prentice Hall, Inc., New Jersey, 2001, pp. 626-650.

[4] Bureau of Public Roads, Traffic assignment manual, U.S. Department of Commerce, Urban Planning Division, Washington D.C, 1964.

[5] H. Spiess, "Conical volume delay functions", *Transportation Science*, vol. 24, No. 2, pp. 1-14, 1990.

[6] S. Ishak and C. Alescandru, "Optimizing traffic prediction performance of neural networks under various topological, input, and traffic condition setting" presented at the Transportation Research Board Journal, Washington D.C., 2003.

[7] J. D. Cutnell and K. W. d Johnson, *Physics*, 5th ed. John Wiley & Sons, Inc., New York, 2001, pp. 28-31.

[8] G. Kanellaidis, "Factors affecting drivers' choice of speed on roadway curves", *Journal of Safety Research*, vol. 26, No. 1, pp. 49-56, 1995.

[9] M. J. Giles, "Driver speed compliance in Western Australia: a multivariate analysis", *Transport Policy,* vol. 11, pp. 227-235, 2004.

[10] B. Crisman, A. Marchionna, P. Perco and R. Roberti, "Operating speed prediction model for two-lane rural roads", presented at the 3rd international symposium on highway geometric design, Chicago, 2005.

[11] A. A. Abdul-Mawjoud and G. G. Sofia, "Development of models for predicting speed on horizontal curves for two-lane rural highways", *Arabian Journal for Science and Engineering*, vol. 33, No. 2B, pp. 365-377, 2008.

[12] C. R. Bennett, "A speed prediction model for rural two-lane highways", PhD. Dissertation, Department of Civil Engineering, University of Auckland, Auckland, New Zealand, 1994.

[13] E. Gallego, M. Moya, A. I. García and F. Ayuga, "Valuation of low volume roads in Spain. Part 1: methodology development", *Journal of Biosystem Engineering (Elsevier)*, vol. 101, pp. 123-134, 2008.

[14] A. Quimby, G. Maycook, C. Palmer and S. Buttress, "The factors that influence a driver's choice of speed – a questionnaire study", Transport Research Laboratory, vol. 325, Transport Research Foundation, Berkshire, 1999.

[15] M. Slinn, P. Guest and P. Matthews, *Traffic engineering design principles and practice*, 2nd ed. Elsevier Butterworth-Heinemann Linacre House, Jordan Hill, Oxford, 2005, pp. 7-27.

[16] R. A. Johnson and G. K. Bhattacharyya, *Statistics principles and methods*, 4th ed. John Wiley & Sons, Inc., New York, 2001, pp. 529-530.