Songklanakarin J. Sci. Technol.
35 (1), 81-90, Jan. - Feb. 2013

SJST SONGKLANAKARIN JOURNAL OF SCIENCE AND TECHNOLOGY
http://www.sjst.psu.ac.th

Original Article

Selection of weigh station locations in Thailand using the analytic hierarchy process

Veeris Ammarapala, Thanwadee Chinda*, Pison Udomworarat, Terdsak Rongwiriyapanich, Amnart Khampanit, Suthathip Suanmali, and Boonyarat Samphanwattanachai

Transportation Research Center, Sirindhorn International Institute of Technology, Thammasat University, Bangkadi, Mueang, Pathum Thani, 12000 Thailand.

Received 2 September 2012; Accepted 11 December 2012

Abstract

The Department of Rural Roads, Thailand, is responsible for managing rural roads and their assets to ensure safe and pleasurable conditions for travelers. Annually, the department spends more than 10,000 million Baht for conducting road maintenances. It has been identified that one of the major causes of road damages is a result of the operations of overloaded trucks. This leads to the plan to establish the weigh stations to control and protect the conditions of rural roads across the country. In order to determine suitable locations for establishing weigh stations, this paper utilizes the analytic hierarchy process technique, with two sets of the main criteria under consideration, namely the engineering and economic factors, with their six associated attributes. The analysis results suggest the criterion weights of the engineering and economic factors, and their associated attributes, to be used for the calculation of the net weights of the rural roads. The roads with the highest net weights are considered feasible for permanent weigh stations establishment.

Keywords: analytic hierarchy process, Department of Rural Roads, Thailand, weigh station establishment

1. Introduction

The Department of Rural Roads (DRR), Thailand, is accounted for maintaining 47,000 kilometers of roads under its responsibility (Department of Rural Roads, Thailand, 2009). Its duty is to construct and repair the roads, and to transfer the technical knowledge to the local governments. Its mission includes: a) developing and improving the rural road standards to support the transportation, tourism, and sustainable city development, b) relieving the traffic problems, by connecting the missing links, and constructing the by-pass roads and shortcuts, and c) acting as a mentor for local government in developing local roads and organizations relatively to the Thai bureaucratic advancement strategy.

* Corresponding author.
Email address: thanwadee@siit.tu.ac.th

To improve and maintain the rural road standard, the department spends high amounts of budget on road maintenances each year. It was investigated that the earlier resurfacing and structural maintenance costs, resulting from the operations of overloaded trucks, were among the highest maintenance costs (Department of Rural Roads, Thailand, 2009). Permanent weigh stations are thus required to control and protect the conditions of rural roads across the country. Based on the Department of Highways (1999), the heavy truck traffic volume was mainly used to position the location of weigh stations. Apart from that, the international roughness index (IRI) and the industrial hub were also recommended for the selection of weigh station locations. Moreover, the Department of Land Transport (2011) mentioned that the products that are normally transported overweight are not only industrial products (e.g. stone, soil, etc.), but also the agricultural products (e.g. rice, sugarcane, etc.). Heap and Tsunokawa (2005) stated that higher average annual daily traffic (AADT) leads to a very poor IRI and a high maintenance cost.

To select the appropriated roads for weigh station establishment, this paper thus utilizes the analytic hierarchy process (AHP) technique to determine the net weight of each rural road with two key factors, namely engineering and economic factors, together with their six associated attributes, including the heavy truck traffic volume, the average annual daily traffic, the proximity to weigh stations of the Department of Highways, the industrial hubs, the agricultural hubs, and the proximity to the industrial estates. The computed net weights of rural roads are compared to select the suitable locations for weigh station establishment.

2. Research Methodology

The methodology of this research study is illustrated in Figure 1. The engineering and economic factors, along with their associated attributes, were first used to define the studied areas, 100 kilometers in diameter. The 100-kilometer area was used to ensure the inclusion of all network roads in the area. The criterion weights of the two main factors together with their six attributes were calculated with the AHP method to determine the net weights of each rural road. The traffic information and road geometry were also employed to decide on the best locations for weigh station establishment.

2.1 Engineering and economic factors

The engineering and economic factors were used to select the suitable roads for weigh station establishment. The engineering factor is represented by three associated attributes, namely, 1) heavy truck traffic volume, 2) importance of the roads as represented by the average annual daily traffic (AADT), and 3) the proximity to the Department of Highway's (DOH) weigh stations. The heavy truck traffic volume represents the risk of severe damages to pavement due to the truck overloading. It is found that the economic zones or the gateways to other countries are the areas that usually have high truck traffic volume (FHWA, 2012). The AADT represents the total volume passing a point or segment of a highway facility in both directions for one year, divided by the number of days in the year (Pathomsiri, 2010). The road that has high AADT usually has high importance (Pathomsiri, 2010). The overloaded trucks usually use detours, especially on the rural roads, to avoid getting fines at the highways' weigh stations (Jetiyanont, 2011). The establishment of weigh station on rural roads closed to those of highway weigh stations would help to suppress the overloaded trucks.

The economic factor is also reflected by three attributes, including 1) industrial hubs, 2) agricultural hubs, and 3) industrial zones. Six industrial products that are normally transported overweight are iron, stone, soil, sand, cement, and petroleum and oil (Department of Land Transport, 2011). Four agricultural products that are normally transported overweight are rice, sugarcane, corn, and cassava (Department of Land Transport, 2011). The establishment of weigh stations in these products' hubs might be necessary for road damaged protection. The rural roads located in the industrial zones should also be given priority in maintaining road infrastructure to enhance the efficiency of people and freight transportations.

The engineering and economic factors, together with their six attributes, were used in selecting the studied areas for weigh station establishment as explained below.

2.2 Studied areas

In selecting the studied areas for weigh station establishment, three steps were involved. First, a number of areas were screened out using the three attributes of the engineering factor. Only the areas that have high heavy truck traffic volume, high importance in terms of AADT, and are close to the DOH weigh stations were chosen for further selection. Second, the economic factors were used to further screen out the studied areas. Again, areas that are both industrial and agricultural hubs, and are in industrial zones were preferred. A number of possible studied areas, 50 kilometers in radius, were then filtered. Last, the final studied area was decided using the scoring system. In this step, each area was rated within the six-subcomponents using the score from 1 to 3, as illustrated in Table 1. The studied area with the highest total score was selected for further analysis with the AHP technique to decide on the best locations for weigh station

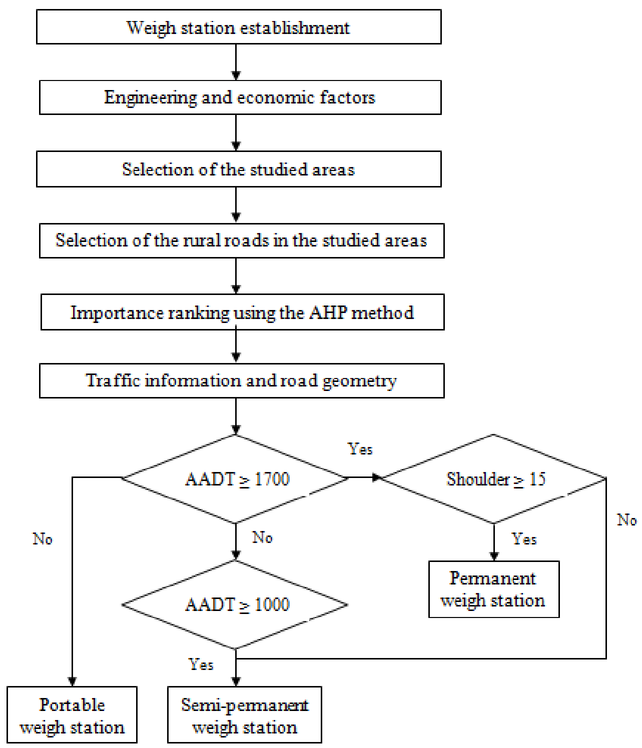


Figure 1. Research methodology of this study.

Table 1. Scoring criteria for the studied area selection.

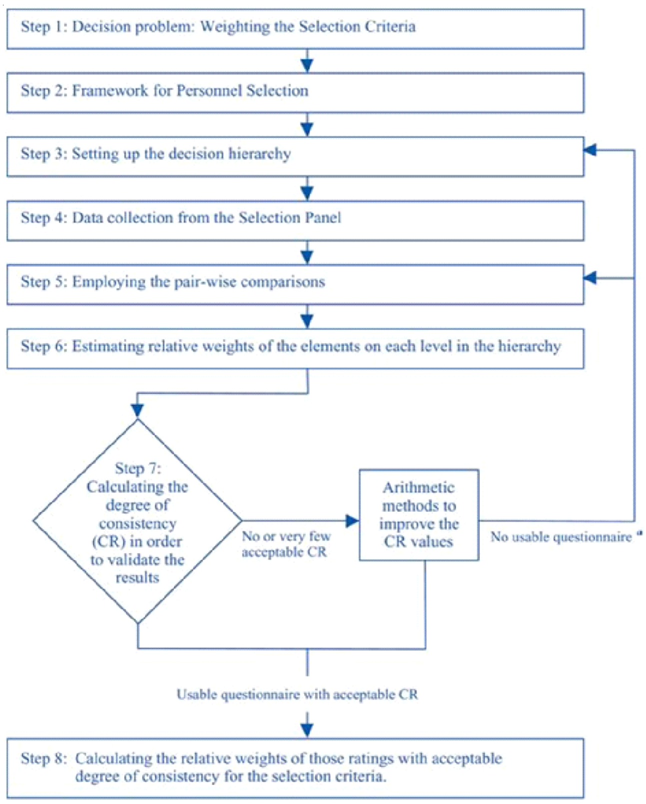
Sub-Component	Score		
	1	2	3
Heavy truck traffic volume	Heavy truck traffic volume of equal to the national average value	Heavy truck traffic volume of above the national average value and less than one standard deviation	Heavy truck traffic volume of above the national average value by at least one standard deviation
AADT	AADT of equal to the national average value	AADT of above the national average value and less than one standard deviation	AADT of above the national average value by at least one standard deviation
Proximity to a DOH weigh station	One DOH weigh station in the area	Two DOH weigh stations in the area	Three or more DOH weigh stations in the area
Industrial hub	Up to 100 plants in the area	100 to 300 plants in the area	More than 300 plants in the area
Agricultural hub	Up to 200 plants in the area	200 to 400 plants in the area	More than 400 plants in the area
Industrial zone	Up to three industrial estates in the area	Three to six industrial estates in the area	More than six industrial estates in the area

establishment.

2.3 The analytic hierarchy process

The analytic hierarchy process (AHP) was developed in the 1970s by T. Saaty. It is becoming popular in research due to the fact that its utility outweighs other research methods (Cheng and Li, 2001). It decomposes a problem into a systematic decision hierarchy, assigns weights to each set of elements at various levels, employs a pair wise comparison to validate the consistency of responses, and determines the priorities of the alternatives (Shapira and Simcha, 2009). Its advantages include the ease of use; the accuracy of the results; the ability to deal with both qualitative and quantitative factors; and the ability to test the consistency of the responses (Rattanavarin, 2007). The AHP method is successfully applied to solve a wide range of multi-criteria decision making problems, for example, a) location analysis, such as the selection of the new international consolidation terminals (Min, 1994), b) evaluation, such as the project evaluation in Taiwan (Liang, 2003), the design of the Chiang Mai bus transit network, Thailand (Sangsana *et al.*, 2008), the ship system risk estimation (Nguyen, 2009), and the evaluation of alternatives in transportation planning (Piantanakulchai and Saengkhao, 2003), c) resource allocation, such as the new personnel recruitment (Cheng and Li, 2001), and d) outsourcing, such as the information technology outsourcing decision (Udo, 2000). According to Cheng and Li (2001), eight steps are required for the AHP analysis, as shown in Figure 2.

The steps start by defining the decision problem. One must ensure that the AHP method is the appropriate method to solve the problem. After that, the decision problem is decomposed into different main components (or factors). A schematic representation of the decision hierarchy is then set based on two assumptions: 1) each factor of a level in the



Note: * A loop jumps back to Step 5 in case of no usable questionnaire. If the "re-comparisons" still cannot reduce the consistency ratio to an acceptable level so that any usable questionnaire can be distilled out, jump back to Step 3 would be necessary

Figure 2. Eight steps of the AHP method.

hierarchy is related to the attributes at the adjacent levels, and 2) there is no hypothesized relationship between factors and attributes of different groups at the same level.

Two factors (engineering and economic) and their total of six attributes in the hierarchy model were then used to develop the interview questions to gather data for the analysis. A personal interview has a major advantage in that it allows the researcher to record not only verbal responses, but also any facial expressions or body movements. These nonverbal responses may give the researcher greater insight into the respondents' true opinions and beliefs (McBurney, 1994). Other benefits include: the respondents can also ask for the questions to be clarified; the researchers can ask follow-up questions, if they think they will provide more reliable data; supplementary material, such as audio/video materials, can be used to increase the respondents understanding of the questions; and the response rates are generally high (Jackson, 2003).

According to Melon *et al.* (2008), six to 12 interviewees were considered appropriated for the interviews to gain greater depth of responses with less cost. Each interviewee was asked to rate the intensity of importance between a pair of factors or attributes, pair-by-pair, using the Saaty's scale of measurement, as explained below.

- Score 1 (equal importance): Two activities contribute equally to the objective.
- Score 3 (moderate importance): Experience and judgment slightly favor one over another.
- Score 5 (strong importance): Experience and judgment strongly favor one over another.
- Score 7 (very strong importance): An activity is strongly favored and its dominance is demonstrated in practice.
- Score 9 (absolute importance): The importance of one over another affirmed on the highest possible order.
- Score 2, 4, 6, or 8 (intermediate values): Used to represent compromise between the priorities listed above.

After all factors and attributes were compared, a paired comparison matrix was formed. In the comparison matrix, the a_{12} score is achieved by comparing component a_1 with component a_2. It must be noted that the a_{12} score is always the reciprocal of the a_{21} score. Subsequently, the estimation of the relative weights of components on each level in the hierarchy was calculated and normalized to sum to 100 percent. After that, the degree of consistency was calculated, utilizing the consistency ratio, CR, to validate the results. The acceptable CR values for different matrices' sizes, as suggested by Saaty (1994), are 0.05 for a 3-by-3 matrix, 0.08 for a 4-by-4 matrix, and 0.1 for larger matrices. In this study, the 2-by-2 matrix (based on the engineering and economic factors), the 6-by-6 matrix (based on the six attributes of the engineering factor), and the 4-by-4 matrix (based on the four attributes of the economic factor) were created, hence, the CR values of 0.05, 0.1, and 0.08 were used to validate the results, respectively. Lastly, the calculated criterion weights were used to estimate the net weight of each rural road. The best decision option, representing the road with the highest net weight, was selected for weigh station establishment.

In this study, the Expert Choice software was used to perform the AHP. It is a multi-attribute decision support software tool that helps a decision maker examine and resolve problems involving multiple evaluation criteria. The software uses the AHP methodology to model a decision problem and evaluate the relative desirability of alternatives.

3. Analyses Results

3.1 Selected studied areas

Three attributes under the engineering factor. The heavy truck traffic volume, the importance of the roads as represented by the average annual daily traffic (AADT), and the proximity to the DOH weigh stations, are used to select the potential areas for weigh station establishment (see Figure 3). It is found that the economic zones or gateways to other countries are the areas that usually have high truck traffic volume. Based on the Department of Rural Roads (2009), 22 areas have high heavy truck traffic volume, i.e. more than the national average value. There are also 22 areas with having higher AADT than the national average value. It, however, must be noted that not all 22 areas that have high truck traffic volume has high AADT. The DOH weigh stations are located in the 38 areas across the country. The establishment of weigh stations close to those areas might help to protect the road conditions by enforcing the carrier companies to carry the loads accordingly to the limits.

Screening out the areas using the above three attributes reveals 11 selected areas, namely Lamphun, Kamphaeng Phet, Khon Kaen, Udon Thani, Nakhon Ratchasima, Nakhon Pathom, Ratchaburi, Chachoengsao, Chon Buri, Samut Sakhon, and Songkhla to be used for further selection. These eleven areas are further analyzed with the three attributes of the economic factor. First, industrial hubs of the six products that are commonly transported overweight are as the followings: 1) main iron hubs are in Samut Prakan, Rayong, Prachuab Khiri Khan, and Chachoengsao areas, 2) main stone pits are in Rayong, Saraburi, Chonburi,

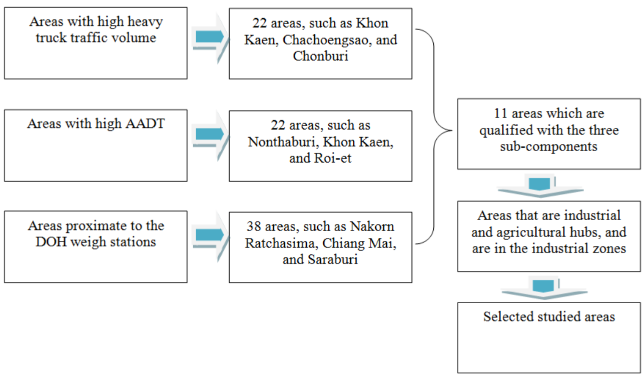


Figure 3. The selection of the studied areas

and Nakhon Ratchasima area, 3) main soil pits are in the east and south of Thailand, 4) main sand pits are in Ayutthaya, Ang Thong, and Sing Buri areas, 5) main cement hubs are in Saraburi, Nakhon Si Thammarat, and Nakhon Sawan areas, and 6) main petroleum and oil hubs are in Chonburi, Rayong, and Bangkok area.

Second, the agricultural products that are normally transported overweight are rice, sugarcane, corn, and cassava. These products are mostly cropped in central and north-east parts of Thailand. Besides, the National and Regional Planning Bureau (2011) recommended Chachoengsao as a logistics and distribution center for agricultural products, as it has transportation networks to the ports, airport, and nearby countries.

Last, the rural roads located in the industrial zones should be given priority in maintaining the road infrastructures to enhance the efficiency of people and freight transportations. The industrial zones in Thailand are mostly located in Rayong, Chon Buri, Bangkok, Chaochoengsao, and Samut Prakan, respectively.

Employing the economic factor screens out eight areas, resulting in three studied areas, namely Chachoengsao, Chon Buri, and Nakhon Ratchasima, for final selection (see Figure 4). Chachoengsao is designated as a logistics hub of the country in the near future. Chon Buri is one of the largest industrial hubs in Thailand. Nakhon Ratchasima is , in contrast, an agricultural hub and a gateway to the north-eastern region of Thailand.

The final three study areas are then compared between each other to decide on the final study area for weigh station establishment. Each area is rated within the six attributes, three from the engineering, and another three from the economic, factors, using the scale from 1 to 3, as explained in Table 1. Interviewing the Head of the Weight Control Office, Department of Highways, revealed that the heavy truck traffic volume and the proximity to the DOH weigh stations should be given a double weight compared with the other four attributes, as these two attributes are considered more important in order to protect from the road damages (Jetiyanont, 2011). The total score of each studied area is then calculated, as shown in Table 2. Chachoengsao is found having the highest score, and is, therefore, selected as the final studied area for weigh station establishment.

3.2 AHP analysis

The AHP method is performed to select the suitable roads for establishing weigh stations in Chachoengsao area. The hierarchy model is developed as shown in Figure 5 with the details as following.

3.2.1 The heavy truck traffic volume

Based on the Department of Highways (1999), a rural road should have at least 1,700 trucks per day in the present year, or 3,000 trucks per day in the next 15 years of its life cycle, to worth establishing a permanent weigh station. If a road has in between 1,000 – 1,699 trucks per day, it should be considered for a semi-permanent weigh station. A portable weigh station is, on the other hand, suitable for a road with less than 1,000 trucks per day. As a result, this study divides the heavy truck traffic volume into three ranges: low, medium, and high, respectively (see Figure 5), with a) a road with low heavy truck traffic volume has 1,000 – 2,350 trucks per day, b) a road with medium heavy truck traffic volume has 2,351 – 3,000 trucks per day, and c) a road with high heavy truck traffic volume has more than 3,000 trucks per day.

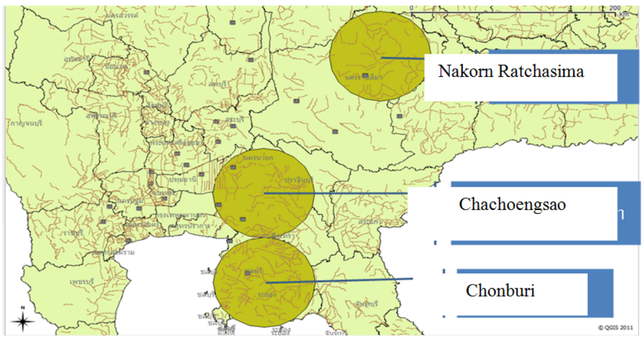


Figure 4. Three final study areas after selection process.

Table 2. Total score of each studied area.

Attribute	Weight	Chachoengsao		Chonburi		Nakorn Ratchasima	
		Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Heavy truck traffic volume	2	2	4	3	6	2	4
AADT	2	2	2	3	3	3	3
Proximity to a DOH weigh stations	1	3	6	1	2	1	2
Industrial hubs	1	2	2	3	3	2	2
Agricultural hubs	1	2	2	1	1	3	3
Industrial zone	1	3	3	3	3	1	1
Total score			19		18		15

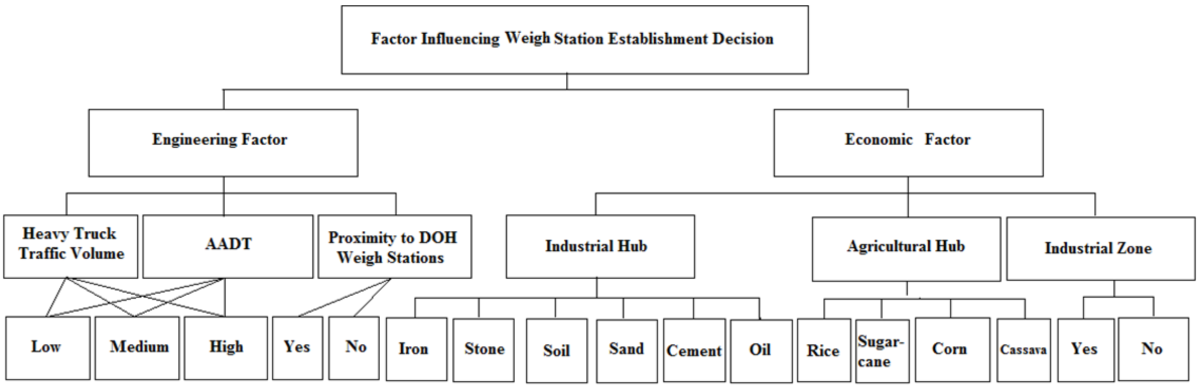


Figure 5. Hierarchy model of the weigh station establishment.

3.2.2 AADT

The importance of the roads is represented by the AADT. In this study, three ranges of AADT are defined, a) a road with low AADT has 2,000 – 4,700 vehicles per day, b) a road with medium AADT has 4,701 – 6,000 vehicles per day, and c) a road with high AADT has more than 6,000 vehicles per day.

3.2.3 Proximity to the DOH weigh stations

Having a weigh station on a rural road that supports the DOH weigh station enhances the efficiency of overloaded control. A rural road is considered more important if it is located closed to the DOH weigh stations.

3.2.4 Industrial hubs

A rural road located in the industrial hubs might experience a problem of the overloaded trucks, which cause road damaged. This study, therefore, considers if a rural road is the hub of the following six key industrial products: iron, stone, soil, sand, cement, and petroleum and oil.

3.2.5 Agricultural hubs

Similar to the industrial hubs, a rural road located in the agricultural hubs must be closely monitored in order to protect the road from being damaged from overloaded trucks. This study considers if a rural road is the hub of the following four key agricultural products: rice, sugarcane, corn, and cassava.

3.2.6 Industrial zone

Rural roads located in the industrial zones are expected to have high heavy truck traffic volume, thus, requiring more attention to protect the proper road conditions.

3.2.7 Criterion weights of factors and attributes calculated from the AHP method

The above six attributes are used to calculate the criterion weights utilizing the AHP method. A total of eight experts were interviewed to gain data information. The experts have high working experiences in the transportation-related area, such as ones in the DOH, Highway Police, and Department of Land Transportation. They were asked to rate the intensity of importance between a pair of factors and attributes using the Saaty's scores. To illustrate, an expert was asked to compare and score between the 'heavy truck traffic volume' and the 'AADT', in order to establish a weigh station.

1) If the expert considers the 'heavy truck traffic volume' and the 'AADT' as having equal importance in weigh station establishment, he then gives the score of 1.

2) If the expert considers the 'heavy truck traffic volume' as having moderate importance in weigh station establishment compared with the 'AADT', then he gives the score of 3, and vice versa.

3) If the expert considers the 'heavy truck traffic volume' as having strong importance in weigh station establishment compared with the 'AADT', then he gives the score of 5, and vice versa.

4) If the expert considers the 'heavy truck traffic volume' as having very strong importance in weigh station establishment compared with the 'AADT', then he gives the score of 7, and vice versa.

5) If the expert considers the 'heavy truck traffic volume' as having absolute importance in weigh station establishment compared with the 'AADT', then he gives the score of 9, and vice versa.

The criterion weights of the engineering and economic factors, as well as their attributes are as shown in Figure 6. The CR values are in the acceptable ranges. These confirm and validate the results. It is clear that the engineering factor has higher weight than the economic factor, with a weight of

0.695. This can be explained that the engineering factor has more influence on the decision to establish a weigh station than the economic factor. Among the three attributes of the engineering factor, the heavy truck traffic volume is found having the highest weight (53.6%); follows by the proximity to the DOH weigh stations (33.2%), and the AADT (13.2%), respectively.

The industrial hub is the most important attribute (weight of 64.2%) among the three attributes of the economic factor. The rural roads located in the stone, soil, and sand hubs should be closely monitored, as they have the highest weights in the industrial hub attribute.

3.3 Selection of rural roads in Chachoengsao area for weigh station establishment

Weights illustrated in Figure 6 are used to calculate the net weight of each of the 46 rural roads in Chachoengsao area. Steps of the calculation are depicted in Figure 7.

To illustrate, the computation of the net weight of the "Chachoengsao – 3001" road is explained in details.

1) This rural road has a relatively high heavy truck traffic volume of 3,343 trucks per day; the weight of the 'heavy truck traffic volume' attribute is then the weight of high heavy truck traffic volume (0.717) times the heavy truck

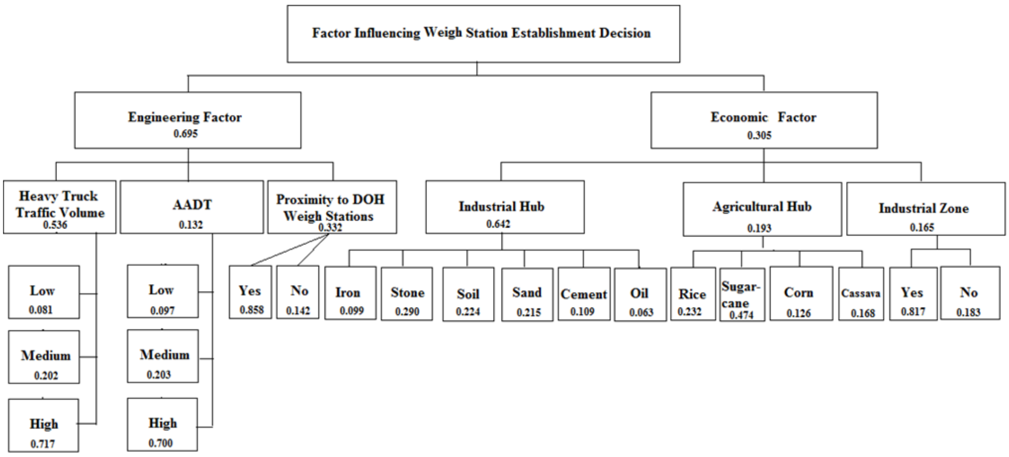


Figure 6. Criterion weights of the engineering factors, the economic factors, and their attributes.

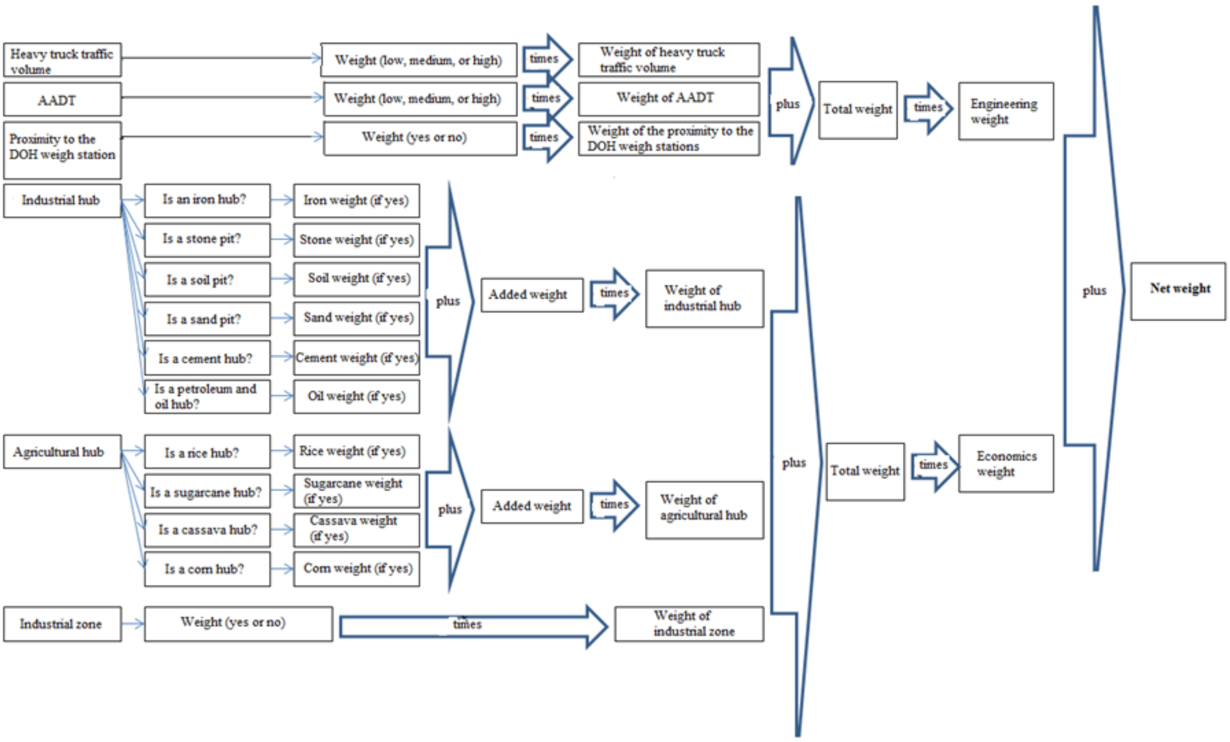


Figure 7. Steps of the net weight calculation.

traffic volume weight (0.536), i.e. 0.717 x 0.536 = 0.3843.

2) This rural road has high AADT of 7,916 vehicles per day; the weight of this attribute is the then weight of high AADT (0.700) times the AADT weight (0.132), i.e. 0.700 x 0.132 = 0.0924.

3) This rural road is located closed to the DOH weigh stations; the weight of this attribute is then the weight of 'yes' (i.e. closed to the DOH weigh stations) (0.858) times the proximity to the DOH weigh stations weight (0.332), i.e. 0.858 x 0.332 = 0.2849.

4) Summing the weights of the three attributes under the engineering factor yields the result of 0.3843 + 0.0924 + 0.2849 = 0.7616. This calculated weight is, then, multiplied by 0.695, which is the engineering factor's weight; the result is the total weight of the engineering factor, which is 0.7616 x 0.695 = 0.5293.

5) This rural road is in the iron pit, soil pit, and cement hub. This yields the industrial hub's weight of (0.099 + 0.224 + 0.109) x 0.642 = 0.2773.

6) This rural road is in the rice, cassava, and corn hubs. This yields the agricultural hub's weight of (0.232 + 0.168 + 0.126) x 0.193 = 0.1015.

7) This rural road is not in the industrial zones; the weight of this attribute is, then, equal to 0.183 x 0.165 = 0.0302.

8) Summing the weights of the three attributes under the economic factor yields the result of 0.2773 + 0.1015 + 0.0302 = 0.4090. This calculated weight is, then, multiplied by 0.305, which is the economic factor's weight; the result is the total weight of the economic factor, which is 0.4090 x 0.305 = 0.1247.

9) Summing the engineering and economic total weights yields a net weight of the "Chachoengsao – 3001" road of 0.5293 + 0.1247 = 0.654 or 65.4%.

The net weights, as well as the recommended types of weigh stations, of the 46 rural roads in Chachoengsao area are illustrated in Table 3. It is found that the 'Chachoengsao – 3001', 'Nakhon Nayok – 3001', and 'Chachoengsao – 3005' roads have the highest weights of 0.654, 0.426, 0.337, respectively. These three roads, therefore, are suitable, both in the engineering and economic points of view, for the establishment of the permanent weigh stations.

4. Conclusion

The establishment of weigh stations on rural roads across the country is important to control and protect road conditions across the country. The engineering and economic factors, with their six associated attributes, namely heavy truck traffic volume, AADT, proximity to the DOH weigh stations, industrial hubs, agricultural hubs, and industrial zones, are used in the AHP method to calculate the net weight of each rural road under the studied area, 'Chachoengsao' area. Data gained from the interviews are utilized in the AHP analysis to calculate the criterion of each factor and attribute. The results reveal that the 'heavy truck traffic volume' on a rural road is most concerned when considering the location of weigh station, with the highest weight of 0.536 or 53.6%.

The criterion weights are then used to estimate the net weight of each rural road. The results show that the 'Chachoengsao – 3001' road has the highest weight among the 46 roads, with the heavy truck traffic volume of more than 1,700 units per day. This rural road should, therefore, be considered first for a permanent weigh station establishment. The results also reveal the 'Nakhon Nayok – 3001' and 'Chachoengsao – 3005' roads as the appropriated roads for establishing permanent weigh stations. The DRR can use the results to help making decisions regarding the weigh station establishments on rural roads in Thailand.

The limitations of this study are as follows: The industrial and agricultural products that are transported overloaded in Thailand might be different from those in other countries. The studied areas could be adjusted to cover the road networks in that area; and the ranges of heavy truck traffic volume and AADT (i.e. low, medium, and high) could be adjusted to match with the traffic volume in the studied areas.

Acknowledgement

The authors would like to thank the Department of Rural Roads, Thailand, for the information support in the project.

References

Cheng, E.W.L. and Li, H. 2001. Analytic hierarchy process an approach to determine measures for business performance. Measuring Business Excellence. 5(3), 30-36.

Department of Highways. 1999. The feasibility study of weigh station establishment on the highways across the country. Report of the Weigh Station Establishment Project, Department of Highways, Bangkok, Thailand (in Thai).

Department of Land Transport. 2011. Top 10 of the truck transportation. Report of the Collection on Truck Transportation Project, Department of Land Transport, Bangkok, Thailand.

Department of Rural Roads. 2009. Background. Department of Rural Roads, Thailand. http://eng1.drr.go.th/node/1620 [January 13, 2012].

FHWA. 2012. Freight and congestion. US Department of Transportation, Federal Highway Administration. http://ops.fhwa.dot.gov/freight/freight_analysis/freight_story/congestion.htm

Hiep, D.V. and Tsunokawa, K. 2005. Optimal maintenance strategies for bituminous pavements: a case study in Vietnam using HDM-4 with gradient methods. Journal of the Eastern Asia Society for Transportation Studies. 6, 1123-1136.

Table 3. Net weights and types of weigh stations on the 46 rural roads in Chachoengsao area.

No.	Rural Road	Net Weight	Truck Traffic Volume (units/day)	Type of Weigh Station
1	Chachoengsao – 3001	0.654	3,343	Permanent
2	Nakhon Nayok – 3001	0.426	2,489	Permanent
3	Chachoengsao – 3005	0.337	2,145	Permanent
6	Nakhon Nayok – 3012	0.290	1,216	Semi-permanent
4	Chachoengsao – 2004	0.315	1,199	Semi-permanent
5	Nakhon Nayok – 2011	0.310	1,088	Semi-permanent
7	Chachoengsao – 3042	0.277	1,886	Permanent
8	Chachoengsao – 6043	0.246	1,825	Permanent
9	Chachoengsao – 3017	0.230	316	Portable
10	Nakhon Nayok – 2003	0.206	50	Portable
11	Nakhon Nayok – 2013	0.206	89	Portable
12	Chachoengsao – 3019	0.205	159	Portable
13	Chachoengsao – 3002	0.196	944	Portable
14	Chachoengsao – 3003	0.173	488	Portable
15	Chachoengsao – 3009	0.164	163	Portable
16	Nakhon Nayok – 2002	0.163	115	Portable
17	Nakhon Nayok – 4008	0.157	174	Portable
18	Nakhon Nayok – 3010	0.134	30	Portable
19	Chachoengsao – 3013	0.131	69	Portable
20	Nakhon Nayok – 4009	0.130	604	Portable
21	Nakhon Nayok – 4016	0.127	26	Portable
22	Nakhon Nayok – 3004	0.121	78	Portable
23	Chachoengsao – 3026	0.106	34	Portable
24	Chachoengsao – 3010	0.100	312	Portable
25	Chachoengsao – 4014	0.094	46	Portable
26	Chachoengsao – 4022	0.094	149	Portable
27	Chachoengsao – 3018	0.085	58	Portable
28	Chachoengsao – 4016	0.075	124	Portable
29	Chachoengsao – 4029	0.073	44	Portable
30	Nakhon Nayok – 4015	0.063	55	Portable
31	Nakhon Nayok – 4020	0.063	99	Portable
32	Nakhon Nayok – 5019	0.061	75	Portable
33	Nakhon Nayok – 5021	0.061	75	Portable
34	Chachoengsao – 4011	0.052	109	Portable
35	Chachoengsao – 6008	0.051	37	Portable
36	Chachoengsao – 3007	0.042	393	Portable
37	Chachoengsao – 3012	0.042	153	Portable
38	Chachoengsao – 6015	0.042	50	Portable
39	Chachoengsao – 6023	0.042	168	Portable
40	Chachoengsao – 4024	0.042	52	Portable
41	Chachoengsao – 3025	0.042	52	Portable
42	Chachoengsao – 6027	0.042	25	Portable
43	Nakhon Nayok – 2005	0.042	102	Portable
44	Nakhon Nayok – 3007	0.042	71	Portable
45	Nakhon Nayok – 4014	0.042	28	Portable
46	Nakhon Nayok – 5017	0.042	48	Portable

Jackson, S.L. 2003. Research Methods and Statistics: a Critical Thinking Approach, Thomson Wadsworth, U.S.A.

Jetiyanont, K. 2011. Personal communication, August 3, 2011.

Liang, W.Y. 2003. The analytic hierarchy process in project evaluation: an R & D case study in Taiwan. Benchmarking. 10(5), 445-456.

McBurney, D.H. 1994. Research Methods. Brooks/Cole Publishing Company, Pacific Grove, California, U.S.A.

Melon, M.G., Beltran, P.A. and Cruz, M.C.A. 2008. An AHP-based evaluation procedure for innovative educational projects: a face-to-face vs. computer-mediated case study. Omega. 36, 754-765.

Min, H. 1994. Location analysis of international consolidation terminals using the analytic hierarchy process. Journal of Business Logistics. 15(2), 25-44.

National and Regional Planning Bureau. 2009. An overview of spatial policy in Asian and European countries. Ministry of Land, Infrastructure, Transportation and Tourism, Japan. http://www.mlit.go.jp/kokudokeikaku/international/spw/general/ thailand/index_e.html#g02 [July 14, 2012].

Nguyen, H. 2009. The application of the AHP method in ship system risk estimation. Polish Maritime Research. 16, 78-82.

Pathomsiri, S. 2010. Super-efficiency directional output distance function: a new mathematical model for ranking social efficiency of transportation systems. Proceedings of the 7th National Transport Conference, Queen Sirikit National Convention Center, Bangkok, Thailand, October 15, 2010, Paper No. 41.

Piantanakulchai, M. and Saengkhao, N. 2003. Evaluation of alternatives in transportation planning using multi-stakeholders multi-objectives AHP modeling. Proceedings of the Eastern Asia Society for Transportation Studies, 4, October. http://www.easts.info/2003proceedings/papers/1613.pdf.

Rattanavarin, S. 2007. Development of Automatic Guided Vehicle (AGV) Controlling System by Radio Frequency Identification (RFID). Master Thesis, Department of Production Engineering, King Mongkut's University of Technology, North Bangkok, Thailand (in Thai).

Saaty, T.L. 1994. How to make a decision: the analytic hierarchy process. Interfaces. 24(6), 19-43.

Sangsana, T., Wankru, N. and Sattayopas, B. 2008. A design of Chiang Mai bus transit network by AHP method. Research on Engineering Project, Department of Transport Engineering, Chiang Mai University, Chiang Mai, Thailand.

Shapira, A. and Simcha, M. 2009. AHP-based weighting of factors affecting safety on construction sites with tower cranes. Journal of Construction Engineering and Management. 135(4), 307-318.

Udo, G.G. 2000. Using analytic hierarchy process to analyze the information technology outsourcing decision. Industrial Management and Data Systems. 100(9), 421-429.