COST-BENEFIT ANALYSIS OF HIGHWAY MAINTENANCE IN THAILAND

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ABSTRACT

The Department of Highways (DOH) is a state agency under the Ministry of Transport, Thailand and is responsible for planning, designing, constructing, and maintaining highway infrastructure throughout Thailand. Highway maintenance is one of the major tasks for the DOH to provide safety and comfort for users. The DOH has also developed one own pavement management model called the Thailand Pavement Management System (TPMS) where the level of International Roughness Index (IRI) is set at 3.50 m/km as a threshold to distinguish between acceptable and unacceptable pavement conditions. This paper attempts to answer how much of the highway network should be maintained at the acceptable level of IRI threshold so that the state welfare will be an optimal condition. Using microeconomic concept, benefit and cost of pavement maintenance are plotted on the same graph where the horizontal axis represents the percentage of the highway network with the acceptable level of IRI. The optimum is where the maximum net benefit, benefit less cost, occurs. On the marginal benefit and marginal cost curves, the optimum point is where the marginal cost and the marginal benefit curves intersect and represents the maximum social surplus condition under microeconomics concepts. Any deviation from the optimum will result in a reduction of the social surplus. This paper also presents a simple optimal allocation with budget constraints where the optimal allocation is formulated as a simple benefit maximization problem and solved by the Lagrange multiplier method. Solutions, obtained from the Lagrange multiplier method, show that at the optimal allocation for a given available budget the marginal benefit of each maintenance activity type divided by the corresponding unit cost should be constant across all activity types. The proposed method has demonstrate itself to be a useful model for pavement management system.

KEYWORDS

Cost-benefit analysis, marginal benefit, marginal cost, pavement management

1. INTRODUCTION

The Department of Highways (DOH) is a state agency under the Ministry of Transport, Thailand and is responsible for planning, designing, constructing, and maintaining highway infrastructure throughout Thailand. It is the DOH mission to create the extensive highway infrastructure network linking with foreign countries, put forward policy and development plan, supervise the construction and carry out the maintenance and restoration of special highways, national highways and concession highways. Moreover, the DOH is in charge of doing analysis, research and development studies, laying down standards and specifications for highways, developing human resources, applying innovative technology, monitoring properly all the activities pertaining to highways to ensure convenience and safety on highways throughout the country and give rise to the economic and social development of the country as well as the political stability of the nation. After road construction was completed and roads were opened for usage, the next important task for the responsible organization is to maintain the usability of that road.

However, the management of limited maintenance budget can be very challenging. Highway maintenance is one of the major tasks for the DOH to provide safety and comfort for users. At present, the network under the jurisdiction of the DOH consists of 68,000 kilometers (2-lane-km) of highways as shown in Figure 1.

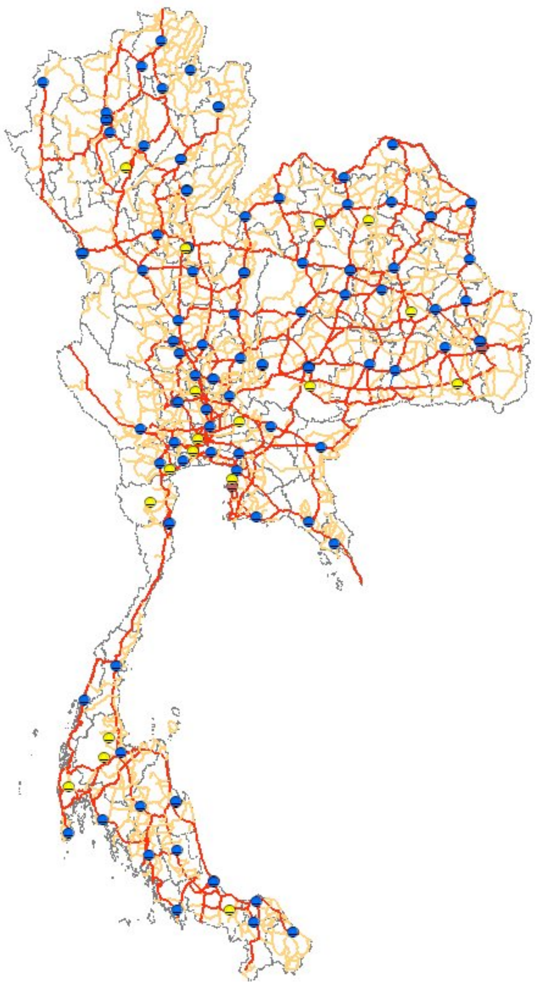

FIGURE 1 The national highway network of Thailand

To maintain these highways, there are more than 130 highway districts performing their maintenance tasks on the daily basis. These districts are located in all regions of Thailand. All highways deteriorate at different rates and exhibit different distressed conditions depending on their utilization and environmental, weather, and geographical conditions as well as other factors such as natural disasters. Therefore, maintenance activities to restore highways to the good serviceable condition must be systematically planned and managed so that every baht (Thai currency) spent on them will economically return benefits to the nation.

Highway maintenance activities at the DOH are classified into four types, namely 1) routine maintenance, 2) periodic maintenance, 3) special maintenance and rehabilitation, and 4) disaster remedy and restoration, each of which functions different purposes. Routine maintenance is the preliminary maintenance activities applied to highway assets to maintain them in good, clean, and safe conditions. It also includes some minor modification and improvement to the existing conditions. Periodic maintenance is a set of activities to be performed periodically to strengthen pavement structures and to extend service life of the highways to serve existing and future traffic. Special maintenance is a set activities applied to highways with distressed conditions and amount of work exceeding those of route maintenance. These activities include surface leveling, asphalt surface repairing, asphalt concrete pavement recycling, and concrete pavement repairing. Rehabilitation is a set of maintenance activities applied to highways with distressed conditions and amount of work exceeding those of special maintenance. These activities include asphalt pavement rehabilitation and concrete pavement rehabilitation. As a consequence, there is an urgent need for an efficient pavement management system that can provide cost-effective solutions to the required highway maintenance activities. Haas, et al (1994) mentioned that good pavement management is not business as usual. Pavement management, in its broadest sense, includes all the activities involved in the planning and programming, design, construction, maintenance, and rehabilitation of the pavement portion of a public work program. It is a set of tools or methods that assist decision makers in finding optimal strategies for providing and maintaining pavements in a serviceable condition over a given period of time. In the 1980s, the DOH utilized pavement management system based on the World Bank system called the Highway Development and Management model (HDM). Along the course of the recent three decades, the DOH has also developed one own pavement management model called the Thailand Pavement Management System (TPMS) where the core element of the TPMS is based on the HDM model but modified to suit Thailand environments and requirements. There are several elements in the TPMS as shown in Figure 2. The TPMS is capable of budget analysis and allocation based on pavement conditions and other relevant data. It facilitates maintenance activity selection and budget allocation according to pavement distressed conditions and appropriate engineering measures. The TPMS has an embedded algorithm with an objective to maximize the benefits of the selected maintenance activities on each highway portion under a limited budget constraint. The system can be used to analyze both operational plans (one-year plans) and strategic plans (multi-year plans) for highway networks in each highway district or for the entire national network. The resulting analyses will provide information on optimal maintenance activities on individual highway sections with the relevant maintenance costs as well as the resulting international roughness index (IRI) values. In addition, the corresponding benefits to road users are also calculated for each selected maintenance treatment and highway section.

The primary factor influencing serviceability of roads is the roughness of the road surface. Roughness evaluation is very important to the pavement management process as it provides the highway authority with a direct measurement influencing the public's perception of the quality of service provided by the pavement. A universal roughness standard has been the subject of extensive discussion and the International Roughness Index (IRI) is widely used internationally. It is the accepted choice of the DOH and is used by many other highway agencies in Thailand. Figure 3 attempts to provide a contextual meaning of the magnitude of IRI. In the metric system, IRI is expressed in m/km. User of the measure must still make decisions as to what is an acceptable level of roughness. The DOH specifies the level of IRI at 3.50 m/km as a threshold to distinguish between acceptable and unacceptable pavement conditions. If there were no budget constraint on highway maintenance, the DOH could maintain the entire highway network at the acceptable IRI threshold or even better. But as a matter of fact Thailand is a developing country whose budget must be allocated to a multitude of development activities that are deemed important to society as a whole. With the limited budget, the DOH should manage the available budget in the most efficient manner. Therefore, the next question to be answered is how much of the highway network should be maintained at the acceptable level of IRI threshold so that the state welfare will be an optimal condition. With this notion, the objectives of this study are:

- To collect relevant data for the TPMS,
- To perform analysis on highway maintenance activities and required costs with the TPMS
- To determine a method that define an optimal condition that define the percentage of the highway network maintained at the acceptable level of IRI threshold of 3.50 m/km.

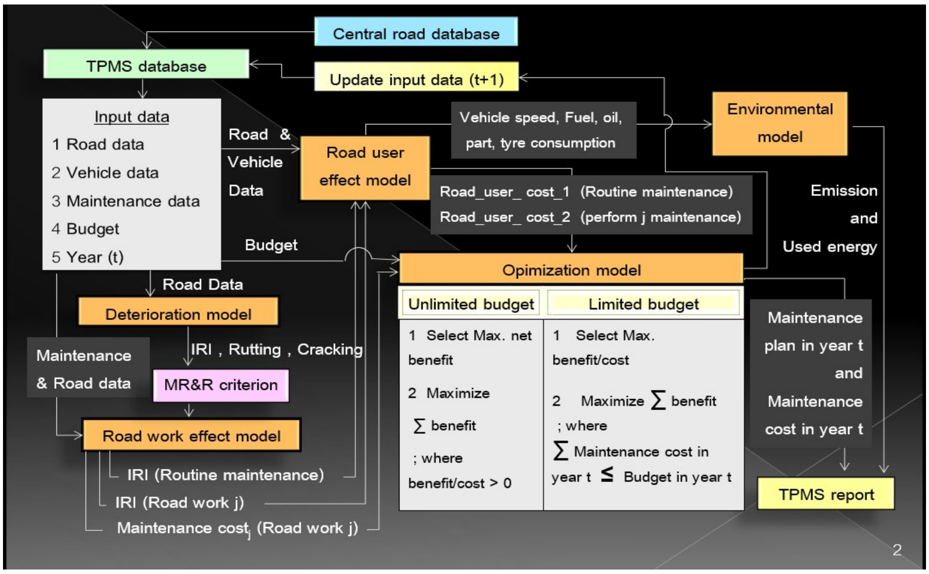

FIGURE 2 The thailand pavement management system (TPMS)

2. COST-BENEFIT ANALYSIS

Modern development has caused changes in all aspects of Thai society. The positive impacts of the development are economic growth, progress of material and public utilities, modern communication systems, and improvement and expansion of education. On the other hand, rapid economic growth and the rise of consumerism has led to a state of economic dependence and deterioration of natural resources. For Thailand, the 1997 economic crisis served as a costly lesson of unbalanced and unstable growth, partly due to the improper economic and social development process. In some countries, due to the economic crisis, the trend of budgetary pressures on highway agencies is increasing. At the same time, road users are increasingly demanding in terms of highway quality, comfort and safety. Several highway maintenance and rehabilitation projects have been delayed because of budget constraints. The economic crisis has also stimulated a wider debate about the state of the road network infrastructure and the consequences of past large investment in new construction and under-investment in projects. During the late 1990s economic crisis in Thailand, the construction of new highways almost ceased and the scarce funds available were used essentially for maintenance and rehabilitation of existing highways. In this section, a simple cost-benefit analysis of highway maintenance activities is introduced to answer the question of how much of the highway network should be maintained at the acceptable level of IRI threshold so that the state welfare will be an optimal condition followed by the analysis on how to optimally allocate limited budgets to different maintenance activities based on microeconomic concepts. The following paragraphs provide the details of the proposed method.

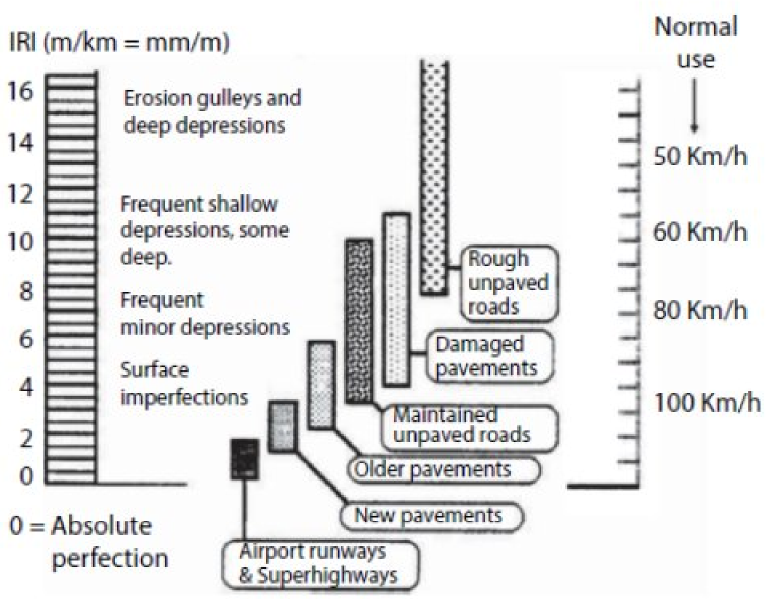

FIGURE 3 Conceptual magnitude of IRI measurements

2.1 Economics of Cost-Benefit Analysis

Boardman et.al. (2011) mentions that cost-benefit analysis is a policy assessment method that quantifies in monetary terms the value of all consequences of a policy to all members of society. The objective is to have more efficient allocation of society's resources. In economics, the quantity demanded is the amount of a good that consumers are willing to buy at a given price during a specified period, holding constant the other factors that influence purchases. The quantity demanded of a good or service can exceed the quantity actually sold. The vertical axis (labeled Price) of the demand curve can be interpreted as the highest price someone is willing to pay for an additional unit of the good. A standard assumption in economics is that demand curves slope downward which is based on the principle of diminishing marginal utility where each additional unit of the good is valued slightly less by each consumer than the preceding unit. For that reason, each consumer is willing to pay less for another unit than for the preceding unit. Indeed, at some point, each consumer would be unwilling to pay anything for an additional unit; his or her demand would be sated. Thus, the area under the demand curve measures the total benefits society would receive from consuming X* units of good X. In a competitive market consumers pay the market price, P*. Thus, consumers spend P*X* to consume X* units. The net benefit to consumers equals the total benefits minus consumers' actual expenditures, (P*X*). This area below the demand curve but above the price line, is called consumer surplus (CS) as shown in Figure 4.

For the supply curve, the quantity supplied is the amount of a good that firms want to sell during a given period at a given price, holding constant other factors that influence supply decisions, such as costs and government actions. The supply curve indicates the marginal cost of each additional unit of the good produced. Thus, the area under the marginal cost curve represents the total variable cost of producing a given amount of good X, say X*. Suppose that the market price of a good is P* and, consequently, firms supply X* units. Their revenue in dollars would be P*X*. Producer surplus (PS) measures the benefit going to firms. It equals the difference between actual revenues and the minimum total revenue that firms must receive before they would be willing to produce X* units at a price of P*, the area under the supply curve as shown in Figure 4.

The sum of consumer surplus and producer surplus is called social surplus (SS). Social surplus is illustrated in Figure 4, which depicts both a demand curve and a supply curve in the same graph. Equilibrium occurs at a price of P* and a quantity of X*. Consumer surplus is the area caP*, producer surplus is the area P*ab, and social surplus is the sum of these areas, cab. Now, net social benefits equals the difference between total consumer benefits and total producer costs. Total consumer benefits equal the area under the demand curve, caX*0, while total costs equal total variable costs, the area under the supply curve, baX*0. The difference is the area, cab. This makes it clear that social surplus equals net social benefits. Remembering that the demand curve reflects marginal benefits (MB) and the supply curve reflects marginal cost (MC), at the competitive equilibrium demand equals supply and marginal benefits equals marginal cost. Therefore, net social benefits are maximized. Either positive or negative deviations from the optimal quantity, X*, will reduce social surplus.

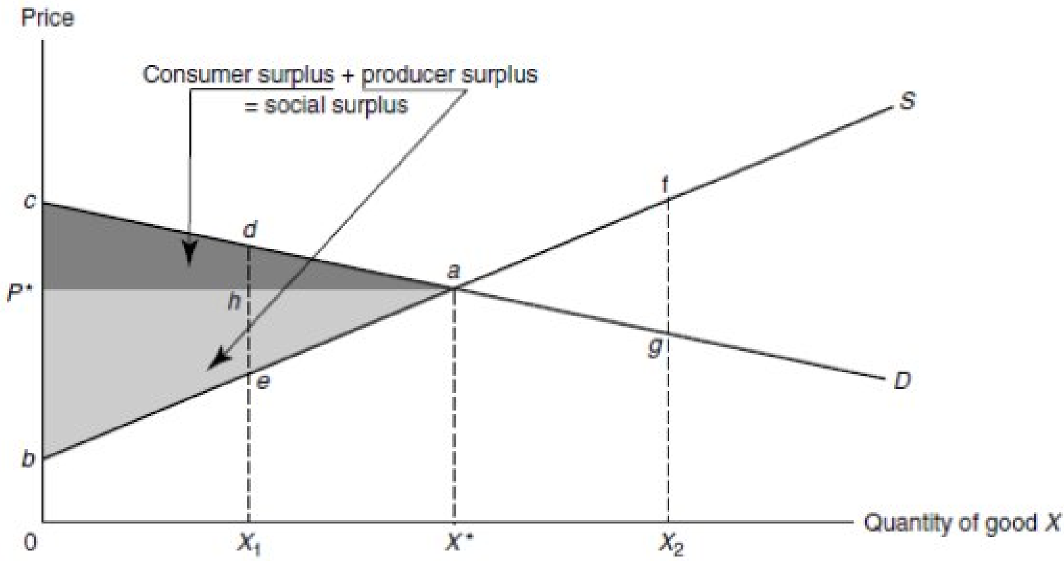

FIGURE 4 Social surplus at equilibrium between demand and supply

Regarding the highway maintenance management, with the outlined microeconomics concept, to evaluate benefits of highway maintenance activities, the DOH uses the TPMS quantifies benefits to road users from 1) savings in vehicle operating costs, 2) reduced road user travel times, and 3) environmental effects where IRI is a primary factor affecting benefits to road users. To estimate costs of highway maintenance activities, unit costs of each maintenance treatment is calculated based on the DOH standards and specifications of maintenance work. By gradually increasing available budgets in the TMPS budget allocation module for highway maintenance activities, benefits and costs associated with each level of the available budgets are calculated from the analysis results. In addition, the resulting percentage of the highway network with an acceptable

IRI of less than 3.50 m/km is estimated for each level of the available budgets. To draw an analogy between microeconomic concept and highway maintenance management, the cost and benefit curves of highway maintenance are plotted on the same graph where the horizontal axis represents the percentage of the highway network with an acceptable IRI of less than 3.50 m/km. Marginal costs and marginal benefits for different percentage of the highway network with an acceptable IRI are plotted on the same graph to identify the optimal percentage of the highway network with an acceptable IRI. The optimum is where the marginal cost and the marginal benefit curve intersect. Please see section 3 for more details.

2.2 Optimal Allocation with Budget Constraint

According to microeconomics, consumers maximize their well-being subject to constraints. And the most important constraint nearly all of us confront in deciding what to consume is the personal budget constraint. Similarly, most highway authorities including the DOH are typically challenged by limited budget constraints on highway maintenance. The TMPS, as outlined earlier, utilizes an optimization module to optimally allocate available budgets to each highway section with appropriate maintenance treatment where an objective function is to maximize the benefit. The formulation of the TPMS optimization model is complex and requires comprehensive mathematical backgrounds. Instead of providing the complex formulation, we present a simple model, borrowed from microeconomics, which can provide an insight into the same concept. Suppose that there are four types of road maintenance activities, each of which has a known unit cost of operations, p_i where an amount of roadwork for each type of maintenance activities is denoted by x_i. The benefit depends on the amount of roadwork done and is denoted by a function $(\; , \; , \; , \;)$. Given the limited budget denoted Y, a simple budget allocation model is represented as:

$$= \quad (\; , \; , \; , \;) \qquad (1)$$

$$\text{st. } p\,x + p\,x + p\,x + p\,x = Y \qquad (2)$$

$$x \geq 0 \;;\; \forall i = 1,2,3,4 \qquad (3)$$

Equation (1) represents an objective function of maximizing the benefit and Equation (2) is the budget constraint. Please note that the benefit function in Equation (1) is a simplified version of benefit, which depends only on the amount of roadwork. But in reality it depends on many other factors such as traffic conditions and pavement conditions. Non-negativity constraints are represented in Equation (3). To solve the above model, Lagrangian method is employed as follows.

$$\mathcal{L} = \quad (\; , \; , \; , \;) + \quad (\quad - \quad - \quad - \quad - \quad) \qquad (4)$$

By differentiating the Lagrangian function, Equation (4), with respect to x_i and , and equating each to zero, we obtain:

$$\frac{\mathcal{L}}{\quad} = \frac{\quad}{\quad} - \qquad = 0 \qquad ; \; \forall \;\; = 1,2,3,4 \qquad (5)$$

$$\frac{\mathcal{L}}{\quad} = \quad - \quad - \quad - \quad - \quad = 0 \qquad (6)$$

= — .... (7)

Taking a closer look at the resulting equations (7) and (6), it means that at the optimum the budget should be allocated in such a way that the marginal benefit of each maintenance activity type divided by the corresponding unit cost should be constant across all activity types. In other words, the benefit is maximized if the last baht (Thai currency) we spend on maintenance activity type 1 get us as much extra benefit as the last baht we spend on maintenance activity types 2, 3, and 4. If the last baht spent on maintenance activity type 1 gave us more extra benefit than the last baht spent on maintenance activity types 2, 3, and 4, we could increase the benefit by spending more on maintenance activity type 1 and less than others. Even though this notion might not entirely be realized in a real-world budget allocation problem, it still provides a rule of thumb for budget allocation problems. The true optimal solution from the more complex method should remain close to the one from this simple model. In the next section, an application of the proposed model is presented.

3. CASE STUDY

In this section, the percentage of the highway network with the acceptable IRI of less than 3.50 m/km is determined by using the proposed method. The cost and benefit curves of highway maintenance from the TPMS results are plotted on the same graph where the horizontal axis represents the percentage of the highway network with the acceptable IRI of less than 3.50 m/km while the vertical axis represents the cost and benefit in bahts. Marginal costs and marginal benefits for each percentage of the highway network with the acceptable IRI are plotted on the same graph to identify the optimal percentage of the highway network with the acceptable IRI. The optimum is where the marginal cost and the marginal benefit curve intersect and it is also the point that the difference between the benefit and the cost is maximized as shown in Figures 5 and 6.

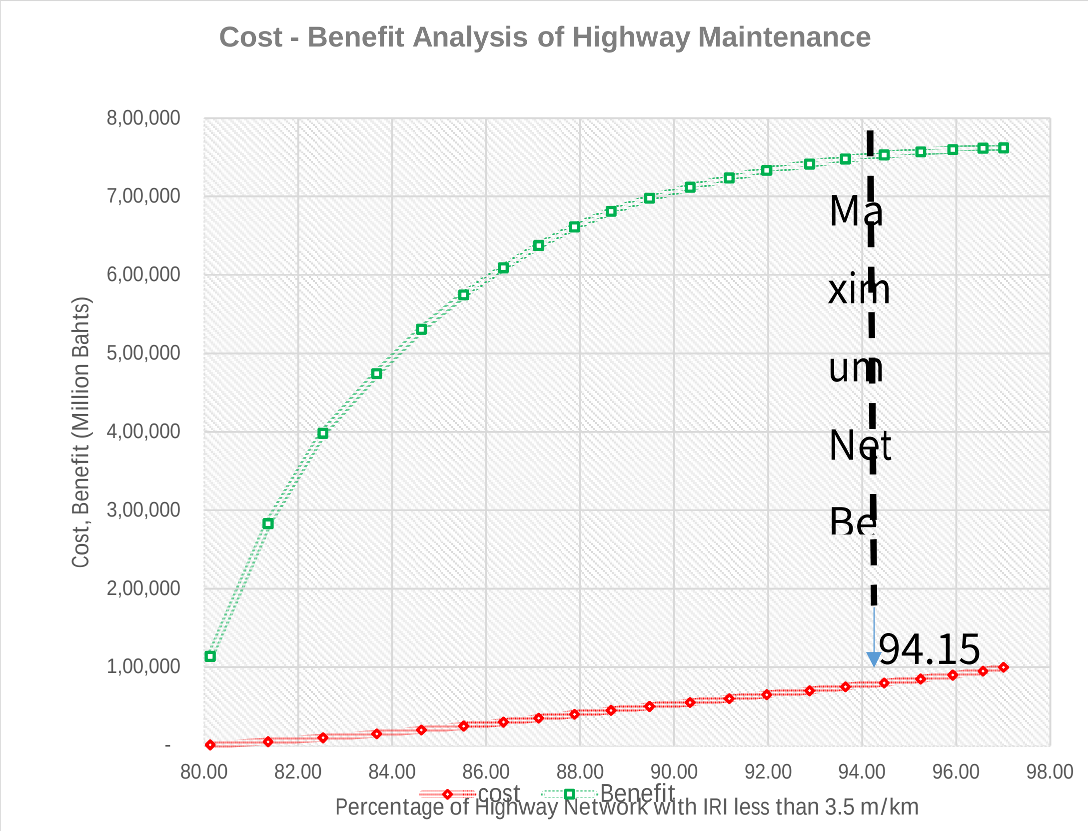

FIGURE 5 Cost – benefit of highway maintenance

It is indicated that the optimal percentage of network with the acceptable IRI less than 3.50 m/km is 94.15 where the social surplus is maximized as shown in Figures 5 and 6. At that point, the required budget is 78,110 million bahts. Supposed that the available budget is only 14,344 million bahts, the social surplus loss is 223,176 million bahts, which is the area of the red triangle in Figure 7. In addition, we also investigate a budget allocation problem by applying the concept of the optimal allocation with budget constraint as outlined in section 2.2. The benefit function in Equation (1) cannot be explicitly written in a mathematical expression because it requires a process of the TPMS calculation to obtain the benefit value for each available budget, which in fact depends on many other factors such as traffic conditions and pavement conditions not just amount of roadwork. However, instead of directly using the proposed formulation in Equations (1) – (3), without knowing the benefit function, we numerically calculate the Lagrange Multipliers expressed in Equation (7) based on the TMPS results to examine whether the Lagrange Multipliers have constant values across all types of maintenance activities for a given budget as shown in Table 1. The results show that the Lagrange Multipliers are quite constant across all types of maintenance activities when the available budget is between 30,000 and 80,000 million bahts. Outside that range, the multipliers are different for different types of maintenance activities. We suspect that the interior solutions from Equations (1) – (3) cannot be found outside that range; therefore, these result in different Lagrange multiplier values. Proportion of each maintenance activity calculated from the TMPS is shown in Figure 8.

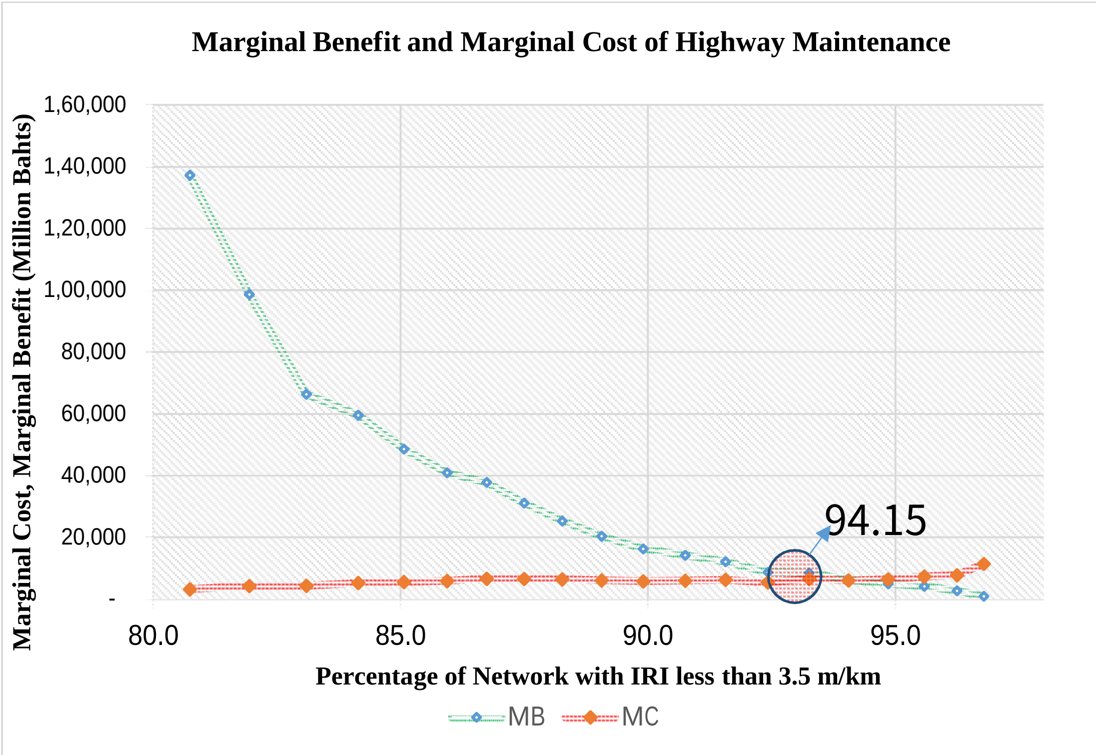

FIGURE 6 Marginal cost and marginal benefit of highway maintenance

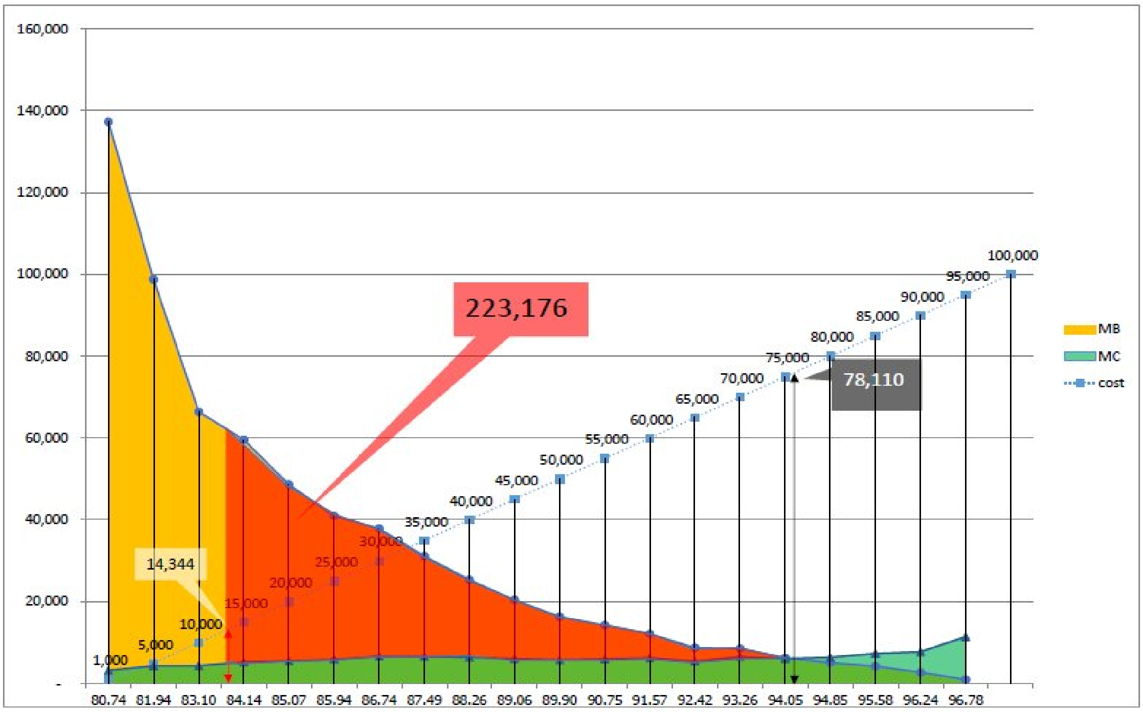

FIGURE 7 Social surplus loss due to non-optimum

TABLE 1 Lagrange Multipliers for Different Maintenance Budgets

Budget (Million Bahts)	Slurry Seal	Overlay 5 cm	Recycling + Overlay 5 cm	Recycling + Overlay 10 cm
17500	10.50	7.63	10.21	12.13
22500	8.40	6.76	8.47	9.27
27500	6.85	5.87	6.87	7.23
32500	5.75	5.12	5.76	5.88
37500	4.86	4.55	4.80	4.84
42500	4.01	3.78	3.99	4.03
47500	3.37	3.26	3.37	3.39
52500	2.84	2.73	2.85	2.87
57500	2.37	2.34	2.38	2.41
62500	1.94	1.92	1.95	2.01
67500	1.59	1.59	1.60	1.62
72500	1.30	1.30	1.30	1.32
77500	1.02	1.03	1.03	0.99
82500	0.79	0.78	0.79	0.89

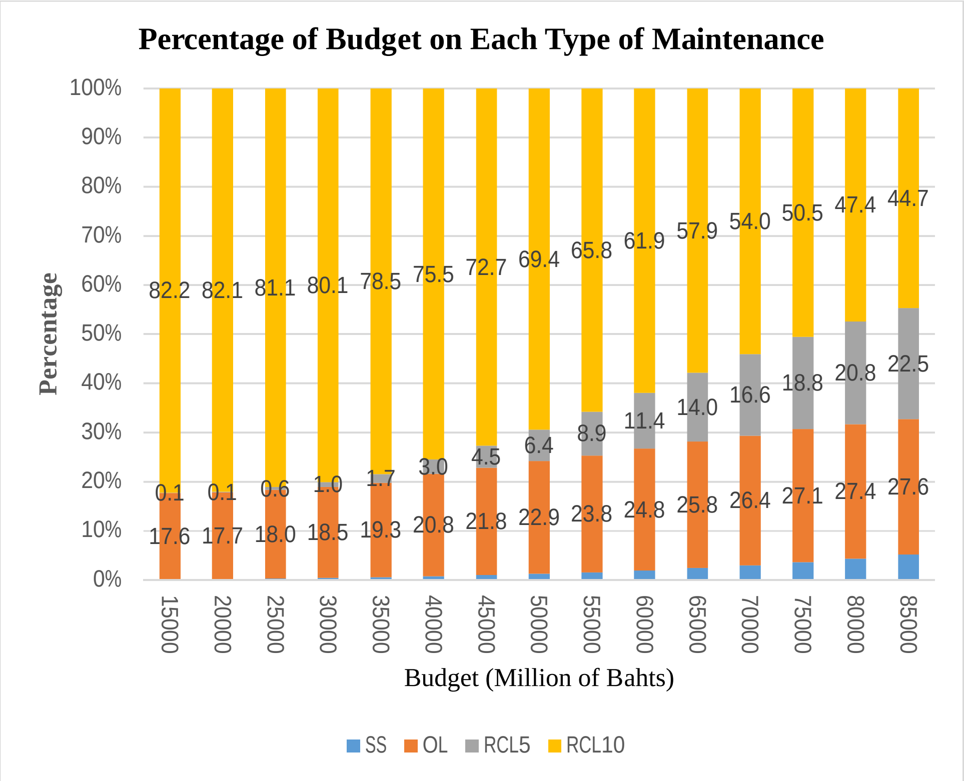

FIGURE 8 Budget Allocation among Maintenance Activities

4. CONCLUSIONS AND FUTURE RESEARCH

In this study, the new method to identify optimal percentage of highway network with an acceptable level of IRI is presented. This optimum represents a point that produces the maximum *net* benefit, benefit less cost, and also represents the maximum social surplus condition under microeconomics concepts. Any deviation from the optimum will result in a reduction of the social surplus. The case study is presented with the Thailand data. In addition, this study also outlines a simple concept of optimal budget allocation with budget constraints where the optimal allocation is formulated as a simple maximization problem and solved by the Lagrange multiplier method. The solution, obtained from the Lagrange multiplier method, shows that at the optimal allocation for a given budget, the marginal benefit of each maintenance activity type divided by the corresponding unit cost should be constant across all activity types. The comparison between the TMPS and the proposed method is made by numerically calculating the Lagrange Multiplier values across all maintenance activity types. It is found that the Lagrange multiplier values are quite constant for most budget ranges. The proposed method has demonstrate itself to be a potential model for pavement management system. In future, we plan to use the proposed method for budget planning of the next Thailand fiscal year.

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