PAVEMENT VALUATION AND PERFORMANCE MEASURES

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Abstract: Performance measure is a key input of infrastructure management system since it helps identify the actual condition of the highway asset(s) and determine the optimal maintenance planning and budgeting. Since the concept of economic stimulation associated with new construction is popular among politicians, a highway agency faces difficulty to convince politicians of the benefits of maintenance management. This study applies the asset valuation concept to measure the relative value of pavement networks under the responsibility of Thailand Department of Highways. Asset valuation expresses the value of an asset in monetary term. It is a useful tool to prepare a financial statement that reflects the actual performance and the deterioration process of an asset for the voters to approve and allocate the annual maintenance budget. Different valuation techniques are discussed in this paper. In addition, two case studies from the Thailand highway network are presented in this paper.

Key Words: pavement performance, pavement valuation, and pavement management system

1. INTRODUCTION

Pavement management system (PMS) concept involves performance measures, prediction modeling, prioritization & optimization and maintenance planning. Performance measures are key inputs into management systems to measure the deteriorated condition of its highway asset(s). Highway agencies have long applied their pavement management system to manage their highways at project and network levels. Thailand Department of Highways (DOH) is one of the largest highway agencies in Thailand that manage and maintain major highway routes in Thailand. DOH had developed and implemented Thailand Pavement Management System (TPMS) in 1984. The original TPMS does not include the engineering economics such as trade-offs analysis for different maintenance alternatives. As a result, the additional module of TPMS is developed which is called TPMS Budgeting Module (N.D. Lea, 1992).

The TPMS Budgeting Module is developed to minimize costs associated with the highway network. It is based on engineering economic comparisons among the different maintenance and rehabilitation options. The application of life cycle cost analysis (LCCA), based on the Highway Design and Maintenance Standards Model (HDM-III) of the World Bank, is applied as an economic tool to determine life cycle costs of different maintenance options. The performance prediction models were calibrated based on the HDM-III concept and the existing TPMS condition assessment. Once the life cycle cost analysis was performed, treatment selection is obtained from TPMS treatment matrix. The treatment matrix provides a set of treatments for each section based on several criteria such as traffic volume and pavement condition. In order to select a proper maintenance treatment, condition assessment, roughness, and traffic volume are required.

The main objective of this paper is to apply the asset valuation concept in order to appraise pavement value. The interrelationships between asset value, performance and time are determined and presented. The highway network under the responsibility of the Thailand Department of Highways is selected as a case study.

2. LITERATURE REVIEWS

2.1 Asset Valuation

The concept of asset management has been introduced in infrastructure management and planning in the past decade. Asset management views an infrastructure as a physical asset and tries to manage an entire asset in the most cost-effective manner. Its key element is to assure how infrastructure practitioners manage and maintain the value of their assets (Haas and Raymond, 1999). One of the economic concepts that measures whether an asset is adequately maintained/managed or not is asset valuation.

Asset valuation is the process of estimating the asset value of a specific asset at a given date. It measures the relative value or wealth of assets for an individual over time (AIREA, 1987). The value of an asset can be implied as market value, use value, investment value, going-concern value, and book value. Value at a given time represents the monetary worth of an asset to a specific stakeholder or stakeholder group such as users and government agencies. The proper definition depends on the usage of the values. Market value is defined as the price in cash for which the specified asset is expected to sell in the market place under all conditions requisite to a fair sale. Since there are very few highway assets sold on the open market, it is very difficult to apply the market value technique to value the pavement. The use value is the value of a particular asset for a specific use. Investment value represents the value of an investment in an asset to a particular investor based on his/her own investment requirements. Going-concern value is the productivity-realized value which measures the net present value of the benefit stream for the remaining service life of an asset (Haas and Raymond, 1999). Going-concern value may be appropriate to value a toll-road, since this type of road generates income over its life cycle.

Asset valuation has been applied in accounting, investment banking and real estate industries. AIREA (1987) stated that asset valuation could be used in ownership transfer, financing and credit, tax matters, and investment decision-making. The application of asset valuation in the area of infrastructure management has been studied in the US and Canada. The Government Accounting Standards Bureau (GASB), a private non-profit entity that issues accounting practices for government agencies in the United States, requires local, state, or federal government agencies to report the value of their infrastructure assets (FHWA, 2000).

2.2 Accounting Basis related to Asset Valuation

Asset value involves two accounting principles which are financial accounting and management accounting (Stantec and the University of Waterloo, 2000). Financial accounting is based on a book value basis. It records all transactions in terms of historical costs. Management accounting is based on replacement cost basis (Stantec and the University of Waterloo, 2000), which records all transactions in terms of the current cost.

2.3 Framework for Highway Asset Valuation

A generic asset valuation framework for highways is recommended by Stantec and the University of Waterloo (2000). The framework is composed of various components which are asset inventory, assessment of current condition, determination of current asset value, and estimation of future asset value. Asset inventory includes type, amount, and location of an asset as illustrated in Figure 1.

2.4 Inventory of Assets

Inventory data includes different characteristics of pavement such as description of section, geometry, pavement structure, costs, environment and drainage, and traffic [Haas *et al.,* 1994].

2.5 Assessment of Current Condition

Assessment of current condition or performance measure is one of the major components in the management system. It is used to assist engineers in identifying and assessing the actual condition of their infrastructures. Performance measures are based on the quality of the level of service, system effectiveness, productivity, efficiency, resource utilization, and cost effectiveness (Hudson *et al.*, 1997). In the past, many performance indices have been developed and implemented to measure the performance of pavement such as IRI, Pavement Condition Index (PCI), and Present Serviceability Index (PSI). In Thailand, three performances indices, which are IRI, major deterioration and minor deterioration, have been used as performance measures in the TPMS Budgeting Module.

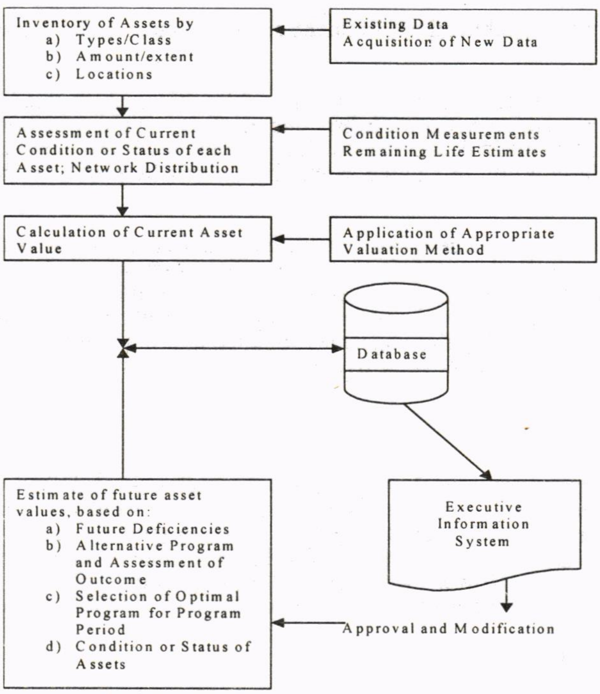

Figure 1:Framwork for Highway Asset Valuation
(Stantec and the University of Waterloo, 2000)

According to TPMS inspection procedures, major deterioration includes potholes, depths of surface damage that are deeper than 20 mm., interconnected cracking, patching, and deflection of pavement. Minor deterioration includes disconnected cracking for both longitudinal and transverse cracking, bleeding, and raveling.

2.6 The Determination of Asset Value

Appraisers estimate asset value by applying specific appraisal techniques. Different valuation techniques are used to estimate different values of the same asset. There are five approaches used in estimating an asset value which are sale comparison, income capitalization, relative valuation, option pricing and cost (AIREA, 1987 and Damondaran, 1996). The selected approach depends on the asset type, the use of its value, and the quality and quantity of the available data.

The sales comparison approach is the most useful technique when a number of similar assets have been sold recently in the market. This approach estimates the value of an asset by comparing the selected asset with the market price of similar properties. The income capitalization approach measures the present value future benefits over the life cycle of an asset. An asset's benefit can be represented in terms of a cashflow stream and its resale value. The discount rate is derived from the acceptable rate of return based on other similar projects. The discount rate reflects the risk of the cashflow estimation. A higher discount rate indicates a higher risk.

In the relative valuation approach, the value of an asset is estimated from other variables of particular assets such as market price, revenue, cashflow, and traffic volume. Option pricing valuation estimates an asset that pays off only under certain circumstance. The World Bank (Crousillate and Martzoukos, 1991) has applied this valuation technique as a decision-making tool for investment in the power industry.

The cost approach is a valuation method whose value is derived by adding the estimated land value to the construction or replacement cost for the improvements and subtracting the depreciation of the asset. The current costs to construct the improvements can be obtained from cost estimators, cost estimating publications, builders, and contractors. Land value is estimated separately in the cost approach.

Depreciation is the decrease in value of a physical facility due to time and/or use (Canada *et al.*, 1996). In the accounting point of view, there are three depreciation methods (Anthony and Reece, 1989), which are straight-line method, accelerated method, and unit of production method. The cost approach is particularly useful in valuing assets that are not frequently exchanged in the market.

According to Figure 1, future asset value is based on the future deficiencies, alternative operation and maintenance programs, selection of optimal programs for program period and condition of the asset. The estimated asset value over time is used to develop the Executive Information System (EIS), which is a computer-based system that supports decision-making processes and prepares financial statements for highway agencies (Stantec and the University of Waterloo, 2000). The EIS helps estimate the asset value over time.

3. METHODOLOGY

Figure 2 illustrates a detailed framework of a proposed integration of TPMS and the asset valuation concept. There are four modules which are database module, asset value-performance-time relationship module, decision analysis module, and output module. Only the first two modules are focused in this paper. The database module contains pavement data that DOH collects. The asset-performance-time relationship module focuses on valuation techniques, land value, pavement construction cost estimates, performance and depreciation.

3.1 Pavement Database Module

This study requires extensive data collection that is used as inputs in the developed module. Data can be classified into several categories as follows:

1. Pavement characteristic inventory, such as road number, control section, location, length, lane width, type of pavement structure, and construction cost, can be obtained from the TPMS database and DOH.
2. Replacement cost and historical construction cost data are available in the form of Bill of Quality (BOQ) at the DOH Construction Division and Districts.
3. Pavement condition data are collected in terms of IRI, major deterioration and minor deterioration from the Maintenance Division of DOH.
4. Traffic volume and its composition are obtained from the Traffic Engineering Division of DOH.
5. Historical maintenance and rehabilitation data for specific control sections and their costs can be obtained from DOH districts.

3.2 Asset Value-Performance-Time Relationship Module

Since many highway agencies are required to prepare the financial statements to illustrate their needs, planning and maintenance activities annually in order to properly allocate their budget, asset valuation is applied in this study to help value each asset and relates the existing performance measures and the deterioration processes. The core relationship between performance and time needs to be modified in order to apply the estimation of asset value. The relationship between performance and time had been developed as deterioration models.

The valuation technique that is applied to determine the pavement value in this study is the cost approach since the cost approach is the only approach that relates asset value, performance and depreciation. AIREA (1987) recommended that this technique is suitable to estimate the market value of assets that are frequently sold in the market. In addition, this technique can be used to value public goods such as highways, bridges, and other public assets. Based on the cost approach, a generic formula to determine asset value at the project level is written as:

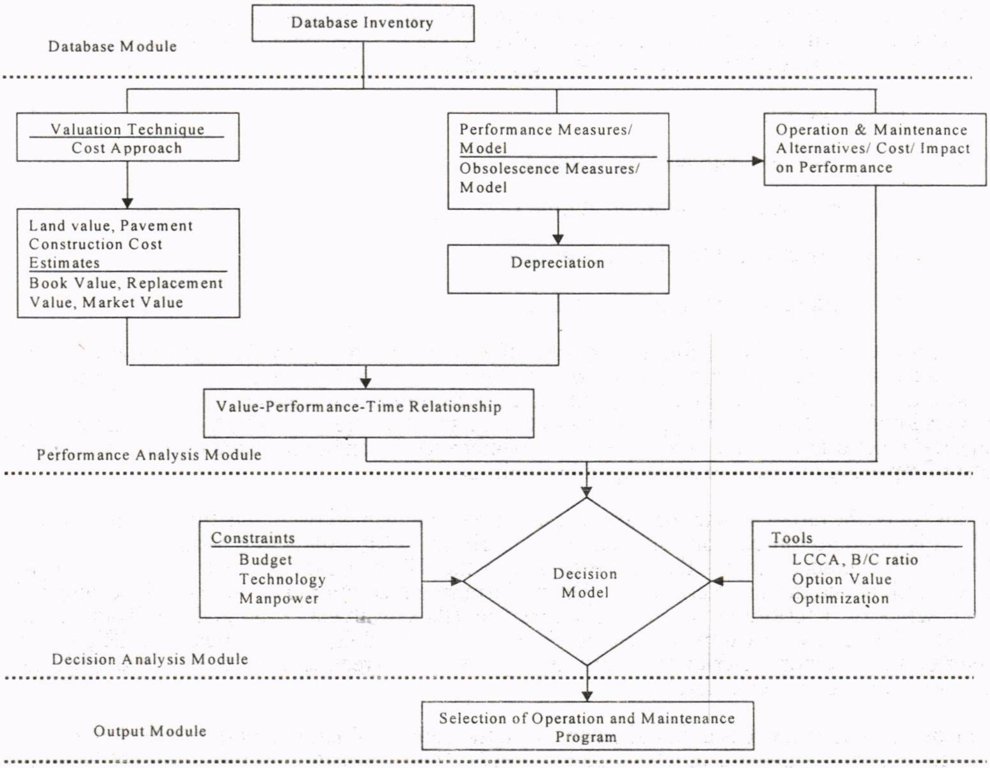

Figure 2: Framework for Suggested Pavement Management System

$$AV_t = L_t + R_t - D_t \tag{2}$$

where AV_t = Asset value at time t

L_t = Land value at time t

R_t = Replacement cost at time t

D_t = Accrued depreciation at time t

There are three main components in equation (2), which are land value, replacement cost of the asset, and accrued depreciation. Land value data is excluded from this study since this study focuses on the relationship of performance and depreciation of a particular pavement section. In this study, replacement cost is applied due to the lack of historical data for construction costs. Replacement cost is assumed to be the construction cost for building a new asset with equal quality. It may not necessarily be constructed with similar materials or with the same specifications. It is estimated based materials used, required labor, the overhead expenses and contractor's profits. Unit cost of all related data are collected from the DOH's districts and headquarters.

Accrued depreciation is a loss of value from replacement cost. Based on the cost technique, a generic equation to determine accrued depreciation is expressed as follows:

$$D_t = f(X_1, X_2, X_3, \ldots, X_n) \tag{3}$$

where D_t is accrued depreciation at time t and $X_1, X_2, X_{3,\ldots,} X_n$ are the attributes. The attributes of accrued depreciation are, for example, traffic volume, service life, socioeconomic and technology. The relationship between depreciation and deterioration is suggested by AIREA

(1987). Depreciation involves three components, which are physical deterioration, functional obsolescence, and external obsolescence (AIREA, 1987). The relationship between accrued depreciation and related attributes can be expressed as follows:

$$D_t = \Delta d_t + f_t + \varepsilon_t \qquad (4)$$

where D_t = Accrued depreciation at time t

Δd_t= Physical Deterioration at time t

f_t = Functional Obsolescence at time t

ε_t = External Obsolescence at time t

Physical deterioration is the loss in serviceability, which is caused by damage or decay in the components of a particular asset (Nutt *et al.*, 1976). The change of performance indices should be reflected in the asset value. When a maintenance or rehabilitation is applied, the condition of an asset is improved and the corresponding asset value should increase. AIREA (1987) defines the physical deterioration as the item of deferred maintenance. It can be measured by determining the cost of repairing the asset to an acceptable condition.

In this study, the physical deterioration is based on a maintenance cost of the different treatments, which is pre-determined from the treatment matrix in TPMS Budgeting Module (N.D. LEA, 1992). Performance indices that are included in the TPMS treatment matrix are IRI, major deterioration, and minor deterioration. The performance prediction over time can be calculated from series of deterioration models developed by (Paisalwattana, 2000 and Jenjiwattanakul, 2001). Maintenance treatments can be determined according to the predicted IRI, major deterioration, minor deterioration and traffic volume. Treatment unit cost and physical deterioration are then calculated.

Functional obsolescence is a loss of value due to the defects of material or design which may be caused by current standards or laws (AIREA, 1987). This is measured by the difference between the cost of addition or modification of an element to meet the new standards and the cost of an element that was installed at the time of original construction. To comply with the current design standard in Thailand, a highway should have 7 meters for pavement width and 2.5 meters for shoulder width. This study assumes that the functional obsolescence is constant over the life cycle of pavement.

External obsolescence is a loss of value according to the change of external factors such as social, technological, economic, governmental, and environmental factors (AIREA, 1987). The change in expectation for the use of a particular infrastructure causes external obsolescence (Lemer, 1996). However, external obsolescence is excluded from this study.

4. CASE STUDIES

This paper selects the highway network under the responsibility of the Thailand Department of Highways (DOH) as a case study. Each DOH highway district is responsible for collecting the pavement condition data annually. These data along with other relevant data are sent to the highway division for further analysis. The highway division then evaluates optimal pavement maintenance activities within their assigned areas and requests maintenance budget from the Maintenance Division at the headquarters based on the analysis from the TPMS Budgeting Module. The maintenance treatment and budget from the TPMS Budgeting Module is determined from the predefined treatment matrix as shown in Table 1.

Table 1. Treatment Matrix for the TPMS Budgeting Module (N.D. LEA, 1992)

	Deterioration		Traffic Range -AADT							
IRI	**Minor**	**Major**	**< 200**	**201-500**	**501-1,000**	**1001-2,000**	**2,000-4,000**	**4,000-6,000**	**6,000-10,000**	**>10,000**
<3	<30 %	<10 %	RM	RM	RM	RM	RM	RM	RM	RM
	>30 %	<10 %	Seal	Seal	Seal	Seal	RM	RM	RM	RM
		>10 %	Seal	Seal	Seal	Seal	OL-50	OL-50	OL-50	REH-AC
3-4	<30 %	<10 %	RM	RM	RM	Seal	OL-50	OL-60	OL-60	REH-AC
	>30 %	<10 %	Seal	Seal	Seal	Seal	OL-50	OL-60	OL-60	REH-AC
		>10 %	Seal	Seal	Seal	Seal	OL-50	REH-AC	REH-AC	REH-AC
4-5	<30 %	<10 %	RM	RM	OL-50	OL-60	OL-60	OL-60	OL-60	REH-AC
	>30 %	<10 %	Seal	Seal	OL-50	OL-60	OL-60	OL-60	OL-60	REH-AC
		>10 %	Seal	Seal	OL-50	OL-60	OL-60	REH-AC	REH-AC	REH-AC
5-6			OL-50	OL-50	OL-60	OL-60	OL-60	REH-AC	REH-AC	REH-AC
6-8			OL-50	OL-50	REH-ST	REH-ST	REH-AC	REH-AC	REH-AC	REH-AC
8-10			REH-ST	REH-ST	REH-ST	REH-ST	REH-AC	REH-AC	REH-AC	REH-AC
>10			REH-ST	REH-ST	REH-ST	REH-ST	REH-AC	REH-AC	REH-AC	REH-AC

where RM = Routine Maintenance
Seal = Slurry Seal or Surface Treatment
OL-50 = 50 mm Asphaltic concrete overlay
OL-60 = 60 mm Asphaltic Concrete Overlay
OL-80 = 80 mm Asphaltic Concrete Overlay
REH-ST = Rehabilitation with Granular Base and Double Surface Treatment
REH-AC = Rehabilitation with Granular Base and 50 mm Asphaltic Concrete

The Maintenance Division prepares annual maintenance budgets for different types of maintenance activities. Each highway division manages and plans the pavement maintenance activities within their assigned areas. Each highway division selects two representative highway districts to submit the summary of its annual pavement maintenance costs to the Maintenance division and the headquarters for further analysis.

Pathumthani district, which was assigned to prepare and submit its maintenance costs, is selected as a case study in this paper. In year 2000, the district is responsible to manage over 360 kilometers of asphaltic concrete highway and 510 kilometers of concrete highway. There are two case studies presented in this paper. The first case study involves a pavement with physical deterioration. It illustrates how to value a pavement whose design is compliant with the design standard used by DOH. Therefore, depreciation only involves the physical deterioration component.

The second case study is the case where both physical deterioration and functional obsolescence exist. Functional obsolescence in the second case is based on the non-compliance of the selected pavement section to the current design standard used by DOH. It shows the techniques of pavement valuation for the case of a pavement whose design is below the standard.

4.1 The First Case Study: Physical Deterioration

The following case study illustrates the valuation of pavement on control section number 3450100 which is a part of route 345. Its pavement material is asphaltic concrete. The basic inventory data of this control section are:

Route	345
Control Section	3450100
Length	13.455 kilometers
Number of Lanes	2 lanes

Lane Width	7 meters
Shoulder Width	2.5 meters
Traffic Volume(1999)	24,892 vehicles per day
IRI (1997)	2.14 m/km
Major Deterioration (1998)	3.84 %
Minor Deterioration (1998)	2.85 %
Last Overlay/Rehabilitation	Year 2000

Without considering land value, the pavement value of this case can be calculated by determining two parameters, which are replacement cost (R_t) and depreciation (D_t). The generic formula which is derived from equation (2) to determine asset value in this case is shown in equation (5) as follows:

$$AV_t = R_t - D_t \quad (5)$$

Replacement Cost

Replacement cost is calculated by the summation of the material used. The value of each material is determined by the quantity of material used and its unit cost. The quantity of material used is determined from the length, width, and thickness of each material level. The unit cost includes the unit cost of material used, labor, overhead expense, and contractor's profit. The determination of replacement cost is summarized in Table 2.

Depreciation

In this case, depreciation is expressed in terms of physical deterioration (Δd_t) as shown in equation (6), which is derived from equation (4).

$$D_t = \Delta d_t \quad (6)$$

The physical deterioration is measured by the required treatment costs to rehabilitate or maintain the structure into a new or an acceptable condition. The treatment for different levels of deterioration can be determined from the TPMS treatment matrix which uses IRI, major deterioration, minor deterioration, and traffic volume as major inputs to select a suitable treatment. Series of developed deterioration models used in this case are selected from (Paisalwattana, 2000 and Jenjiwattanakul, 2001) and presented in equations (7), (8), and (9) The prediction models predict the future condition of the pavement which helps identify the required treatments and their costs in the future.

$$IRI = 2.203 * e^{(0.109*N)} \quad (7)$$

$$Y = 0.2559X_1^2 + 2.4185X_1 \quad \text{(Major Deterioration)} \quad (8)$$

$$Y = 0.00165*(X_1^{0.39766})*(X_2^{0.39601}) \quad \text{(Minor Deterioration)} \quad (9)$$

where IRI= Forecasted IRI
N = Time Service
Y = Percentage of Deteriorated Area
X_1 = Change of Time Service
X_2 = Change of Cumulative Equivalent Single Axle Load

According to DOH policy and the HDM-III model, the time for major rehabilitation is set at the seventh year after construction or previous major rehabilitation. In this case, the last overlay was performed in year 2000. Therefore, the base year of the pavement value in this case is year 2001. The results of forecasted IRI, major deterioration, minor deterioration and suitable treatments for each year are illustrated in Table 3.

Table 2. The Determination of Replacement Cost of Pavement Section

Material	Thickness (cm.)	Unit Price (Baht/m^2)	Quantity (m^2)	Element Value (Baht)
Sand	140	707	94,185	66,529,195
Aggregate	5	8.6	94,185	809,114
Crush Rock	20	102.4	94,185	9,643,979
Prime Coat	Standard	19.02	94,185	1,791,834
Asphaltic Concrete	4	140.33	94,185	13,216,925
Tack Coat	Standard	5.64	94,185	530,753
Asphaltic Concrete	4	140.33	94,185	13,216,925
Tack Coat	Standard	5.64	94,185	530,753
Asphaltic concrete	4	140.33	94,185	13,216,925
Total Replacement Cost				**119,486,402**

Table 3. The Determination of Performance Indices and Treatment

Year	IRI (m./km.)	Major Deterioration	Minor Deterioration	Treatment to Restore Condition
2001	2.46	2.52	2.67	Routine
2002	2.74	4.37	5.86	Routine
2003	3.06	6.03	9.56	OL-60
2004	3.41	7.58	13.77	OL-60
2005	3.80	9.05	18.49	OL-60
2006	4.24	10.46	23.72	REH-AC
2007	4.72	11.82	29.47	REH-AC

According to Table 3, the treatment to restore the pavement condition is selected based on a TPMS pre-specified treatment matrix. Routine maintenance is referred to regular maintenance work such as patching. The calculation of treatment cost is based on the formulas, which are internally developed by DOH (DOH, 1992). The treatment costs of different treatment types are shown in Table 4.

Pavement Value

With the estimated replacement cost and the depreciation, the pavement value of the selected pavement section is calculated. The detailed calculations of pavement value for each year are presented in Table 5 and Figure 4. According to Figure 3, there is a strong relationship between pavement value and time since R^2 is 0.8904 which is considered to be strongly correlated. The result from the regression analysis for this case is presented in equation (10)

$$Y = -(0.3482*X^2)-(8.8489*X)+129.23 \quad (10)$$

where Y = Forecasted Pavement Value
X = Time Service

Table 4. The Determination of Maintenance Treatment Cost

Treatment Type	Unit Price (Baht/m^2)	Quantity (m^2)	Element Value (Baht)
Routine Maintenance	4.83	94,185	454,641
Overlay A/C 60 mm.	216.13	94,185	20,356,140
Rehabilitation A/C	365.32	94,185	34,407,285

Table 5. The Determination of Pavement Value

Year	Replacement Cost (Baht)	Physical Deterioration (Baht)	Pavement Value (Baht)
2001	119,486,402	454,641	119,031,762
2002	119,486,402	454,641	119,031,762
2003	119,486,402	20,356,140	99,130,262
2004	119,486,402	20,356,140	99,130,262
2005	119,486,402	20,356,140	99,130,262
2006	119,486,402	34,407,285	85,079,117
2007	119,486,402	34,407,285	85,079,117

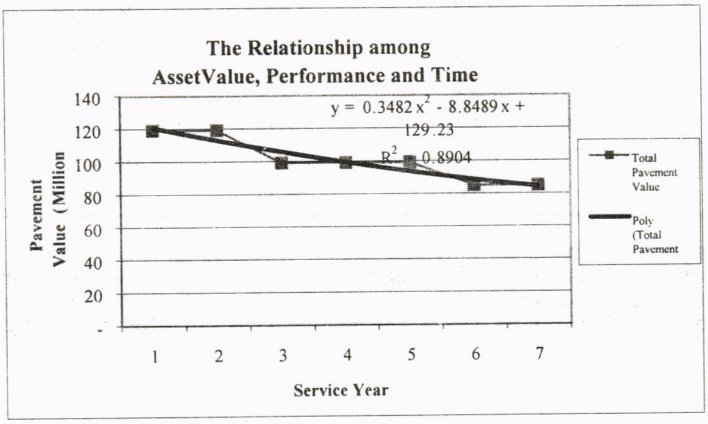

Figure 3. The Relationship among Pavement Value, Performance and Time

4.2 The Second Case Study: Physical Deterioration and Functional Obsolescence

The following case study illustrates the valuation of pavement on control section number 33090101 which is a part of route 3309. Its pavement material is asphaltic concrete. The basic inventory data of this control section are:

Route	3309
Control Section	3309101
Length	19.55 kilometers
Number of Lane	2 meters
Lane Width (m.)	5 meters
Shoulder Width	1.75 meters
Traffic Volume	7,405 vehicle per day
IRI (1997)	2.77 m/km
Major Deterioration (1998)	N/A

Minor Deterioration (1998) 2.55 %
Last Overlay/Rehabilitation Year 1998

This case study involves both physical deterioration and functional obsolescence since the selected pavement section does not comply with the current design standard used by DOH. DOH has set their road standard to be 7 meters for pavement width and 2.5 meters for shoulder width. The steps of the calculation are similar to the previous case with the additional calculation of functional obsolescence.

Replacement Cost

Replacement cost is calculated as the summation of element value of all materials used. The calculation of replacement cost for this case is summarized in Table 6.

Table 6. The Determination of Replacement Cost of Pavement Section

Material	**Thickness** (cm.)	**Unit Price** (Baht/m^2)	**Quantity** (m^2)	**Element Value** (Baht)
Sand	70	114.1	107,569	12,310,707
Selected Material	40	58.4	107,569	6,286,440
Aggregate	15	22.2	107,569	2,380,408
Crush Rock	20	93.6	107,569	10,068,458
Prime Coat	Standard	14.96	107,569	1,609,130
Asphaltic Concrete	5	125.0	107,569	13,498,891
Total Replacement Cost				46,153,388

Depreciation

In this case, depreciation is comprised of two elements, which are physical deterioration (Δd_t) and functional obsolescence (f_t). The generic formula, which is derived from equation (4) to determine depreciation, is shown in equation (11) as follows:

$$D_t = \Delta d_t + f_t \quad (11)$$

As discussed in the first case study, the treatments for different level of deterioration are determined based on the predicted performance. Equations (8) and (9) are used to predict major and minor deterioration of the selected pavement section in this case. However, the deterioration model that relates IRI and the time service is changed based on the different traffic volume and percentage of heavy vehicle as illustrated in equation (12) (Paisalwattana, 2000 and Jenjiwattanakul, 2001):

$$IRI = 2.222 * e^{(0.087*N)} \quad (12)$$

Where IRI = Forecasted IRI
N = Time Service

The last overlay of this case was performed and completed in year 1998, therefore the base year of the second case is year 1999. The result of forecasted IRI, major deterioration, minor deterioration and a suitable treatment to restore an acceptable condition level of this pavement section for each year are illustrated in Table 7. The calculation of treatment cost is based on the formulas which are internally developed by DOH (DOH, 1992). The treatment costs of different types of treatment are shown in Table 8.

Functional Obsolescence

The functional obsolescence is determined by the difference of the cost of addition or modification of an element to meet the new standard and the cost of an element that was installed at the time of the old construction. According to the design standard used by DOH, a road should have 7 meters for pavement width and 2.5 meters for shoulder width. Based on DOH's actual practice, in order to improve this pavement section to comply with the new design standard, the existing asphaltic concrete has to be removed and additional pavement and shoulder will be constructed. The functional obsolescence of this pavement section is the treatment cost to excavate existing asphaltic concrete and the overlay cost. Table 9 summarizes the calculation of functional obsolescence.

Table 7. The Determination of Performance Indices and Treatment

Year	IRI (m. /km.)	Major Deterioration	Minor Deterioration	Treatment to Restore Condition
1999	2.42	0.91	2.67	Routine
2000	2.64	1.58	5.86	Routine
2001	2.88	2.18	9.56	Routine
2002	3.15	2.74	13.77	OL-50
2003	3.43	3.27	18.49	OL-50
2004	3.74	3.78	23.72	OL-50
2005	4.09	4.28	29.47	OL-60
2006	4.46	4.75	35.73	OL-60
2007	4.86	5.22	42.49	OL-60

Table 8. The Determination of Maintenance Treatment Cost

Treatment Type	Unit Price (Baht/m^2)	Quantity (m^2)	Element Value (Baht)
Routine Maintenance	4.83	107,569	519,558
Overlay A/C 50 mm.	130.67	107,569	14,055,639
Overlay A/C 60 mm.	155.76	107,569	16,755,417

Table 9. The Calculation of Functional Obsolescence

Treatment Type	Unit Price (Baht/m^2)	Quantity (m^2)	Element Value (Baht)
A/C Excavation	5.17	107,569	556,132
Prime Coat	14.96	107,569	1,609,130
Overlay A/C 50 mm.	125.49	107,569	13,498,891
Total			15,644,152

Pavement Value

Based on the replacement value, depreciation which includes physical deterioration, and function obsolescence, the pavement value of the studied pavement section can be calculated. The detailed calculations of pavement value for each year are shown in Table 10. In addition, the results of pavement value are presented in Figure 4. According to Figure 4, there is strong relationship between pavement value and time since R^2 is 0.8196, which is considered to be highly correlated. The regression equation of this case is illustrated in equation (13)

$$Y = -(38.848 * e^{-0.1294X})$$

where Y = Forecasted Pavement Value
X = Time Service

Table 10. The Determination of Pavement Value

Year	Replacement Cost (Baht)	Physical Deterioration (Baht)	Functional Obsolescence	Pavement Value (Baht)
1999	46,153,388	519,558	15,644,152	29,969,990
2000	46,153,388	519,558	15,644,152	29,969,990
2001	46,153,388	519,558	15,644,152	29,969,990
2002	46,153,388	14,055,639	15,644,152	16,433,597
2003	46,153,388	14,055,639	15,644,152	16,433,597
2004	46,153,388	14,055,639	15,644,152	16,433,597
2005	46,153,388	16,755,417	15,644,152	13,753,819

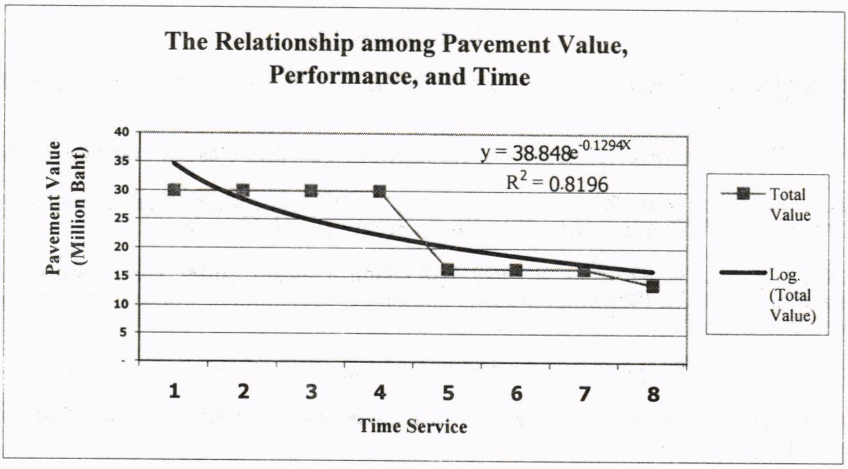

Figure 4. The Relationship among Pavement Value, Performance and Time

5. DISCUSSIONS AND CONCLUSIONS

This paper proposed a framework of the integration of asset valuation concept and pavement management system. Based on the proposed framework, this paper discusses two modules, which are pavement database module and asset value-performance-time relationship in detail. Pavement database module involves the pavement data of Thailand Department of Highways (DOH). Asset value-performance-time relationship module studies the relationship between asset value, performance and time. The relationship between performance and time was studied by many researchers around the world under the deterioration-modeling concept, which predicts the future condition of the pavement based on many dependent variables. However, the modification or the addition of asset valuation into the relationship of condition and time requires extensive data collection and an existing systematic management system.

Various asset valuation techniques are reviewed to determine the most appropriate approach. The cost approach is selected in this study since it is the only approach that relates the asset value, performance and time. Based on the cost approach, asset value at a particular time is based on land value, replacement cost, and accrued depreciation at time of valuation. Accrued depreciation is a function of physical deterioration, functional obsolescence, and external obsolescence.

There are two case studies presented in this paper. The first case study involves the pavement valuation with physical deterioration. The second case study is the case that has both physical deterioration and functional obsolescence. Instead of presenting the pavement sections by their condition indices or required treatments through time, the pavement value of both cases are calculated and presented in monetary terms based on its performance and deterioration process. It is obvious that as time goes, the deterioration progresses which yields the lower value of pavement sections. In both cases, highly correlated relationships between pavement value and time are developed.

The developed relationship between pavement value and time is the starting point of the integration of asset valuation to an existing management system and further to an asset management system. The relationships of asset value and other factors such as traffic and environment should be further investigated.

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