Criterions of PMS Introduction, Evaluation and Future Improvement way

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When road agencies seek to introduce, evaluate or improve their Pavement Management System (PMS), there is often confusion due to a lack of long-term PMS development strategy. Development of PMS is never easy, because it demands comprehensive understanding of current situations and knowledge of PMS. In fact, many road agencies have relied on others' experiences or ready-made software not well suited to their own PMS situation. When agencies make wrong choices, the decision process must begin again, which requires extra expenditure of money and time, compounding social costs. Obviously, a PMS model should be developed step by step with a well-grounded long-term PMS development plan. As fundamental research on PMS, this paper aims to foster sustainable development of PMS models by suggesting criteria for the introduction of PMS and for ways in which the system can be improved. As criteria, 1) a general PMS framework, 2) the standardization of PMS capability level, 3) a definition of PMS functions and 4) data requirements and management are treated as the main focus of research. These criteria are expected to serve as a useful guideline for the initial introduction, self-examination, and extension of PMS capabilities. While this research may be usefully applied to individual cases, a much more important goal is to establish compatibility among PMS models. Mitigating heterogeneity among PMS models can greatly benefit the PMS world. In addition, the criteria could serve as a foundation for various undertakings in PMS research regarding such matters as PMS databases, PMS cycle management, pavement deterioration forecasting, and life cycle cost analysis models.

Key Words : *criteria of PMS development, PMS functions, framework of PMS, PMS evaluation, data requirements of PMS*

1. INTRODUCTION

The pavement management system treats the past, present and future of pavement. It systematically accumulates pavement history data (past), and operates the management cycle (present). Based on maintenance history, a better maintenance strategy (future) can be established. To apply the benefits of the PMS, a road agency should invest sufficient time and effort in defining the best PMS from the first implementation. Obviously, the best PMS does not mean a system which has powerful functions, but a system which well describes the road agency's PMS environment and objectives. This is why self-development is essential to ensure flexibility in reflecting the current situation and future demands. Well-designed PMS development criteria may facilitate sustainable PMS development.

Although road agencies desire a trustworthy guide that leads to successful PMS development, criteria, standards, or specifications have not been treated as important issues, perhaps because the heterogeneous PMS situations of each country make a universal guide meaningless. However, a PMS development strategy is the most fundamental factor that should be established at the outset of PMS implementation. For sustainable PMS development, firstly road agencies should have a clear grasp of their current PMS situation, and draw blueprints for their desired PMS. To accomplish these processes, it is necessary to express PMS situations with a standardized index, which should be well matched with general (or best) improvement trends of PMS from the beginning stage to a mature level. The PMS evaluation index is useful for self-evaluation, and for the design of methods for future improvement. With the definition of PMS situations, PMS functions satisfying PMS capability levels can be defined. Naturally, a general framework for a PMS at each level also can be established. After attending to these details, we will discuss data requirements. This is the outline of our paper.

The suggested criteria are expected to produce three benefits. First, the criteria can be referred to by every individual trying to introduce or improve a PMS model. In this way, the criteria may directly benefit each road agency. Second, when road agencies apply the criteria, their PMS will then have (partial) compatibility with others who follow the criteria. Common criteria could mitigate heterogeneity in PMS models while allowing heterogeneity in PMS situations. Lastly, the criteria can be used as a starting point for other PMS research.

One limitation of the criteria is that they are still unilaterally developed standards. However, the criteria will likely be improved by the continuous feedback of many road agencies in various PMS situations. Finally, the idea of creating standard criteria brings us closer to bilateral, or multilateral, criteria that could be considered an international standard for PMS development. Note that the term "PMS development" used in this paper has a comprehensive meaning that includes any effort to introduce or improve PMS. Issues related to road construction are beyond the scope of this paper.

2. LITERATURE REVIEW

Much literature has treated the details of asset management, infrastructure management, or facilities management[1)-8)]. As major references in the PMS sector, Hudson *et al.*[1)], Goodman and Hastak[2)] and Fwa[6)] well describe overall concepts and concerns of infrastructure management, and summarize general methodologies used in PMS. They present a huge amount of information on detailed methods and experiences related to infrastructure management. However, instruction regarding PMS development strategy has been inadequate. Huang[4)] and Shahin[3)] introduce very practical information in works similar to field manuals, which could serve as valuable references facilitating the operation of the PMS management cycle. Nam[5)] suggests advanced stochastic optimization methods for infrastructure management. The models would be useful in the development of pavement deterioration forecasting models in various cases. The MLTM[8)] is a national guideline for investment in road infrastructure in Korea, treating a wide range of Life Cycle Cost (LCC) evaluation methods related to road infrastructure. This kind of guidebook makes it easy to define PMS models. Among our references, Shahin[3)] suggests pavement management implementation steps based on ready-made PMS analysis software, the Micro PAVER. The steps are widely divided: 1) obtain map, 2) define network, 3) collect inventory data, 4) create database, 5) collect condition data, 6) develop deterioration models, 7) verify data, 8) obtain localized and global M&R (Maintenance and Rehabilitation) costs, 9) develop PCI (Pavement Condition Index) vs. cost models, 10) perform condition analysis and work planning analysis, 11) formulate M&R project and establish priorities. While the noted steps are sufficient to cover the basic procedures of road agency-oriented PMS analysis, they would be insufficient to cover various objectives extended to road user costs and socio-environmental issues. In addition, the steps treat only agency-oriented analysis.

As noted above, most references well summarize essential PMS components and present details on various methods, models and technologies. Nevertheless, it is difficult to find suitable references about PMS development strategy at the system level, since references are usually dedicated to individual components at the functional level. However, all references would be useful for designing PMS functions after a PMS development strategy is defined.

3. PHILOSOPHIES FOR SUSTAINABLE PMS DEVELOPMENT

For sustainable PMS development, this paper advocates taking a more long-term view, whereby standard PMS would be universally applied as a matter of course. In reality, however, it is very difficult to realize this goal. Most road agencies, accustomed to their current routines, wish to maintain the status quo and are reluctant to make the troublesome changes that switching PMS systems would require. Properly, their interests and perspectives remain at past or present levels. One good example is data policy. PMS development depends on the definition of 1) the roles of PMS, 2) PMS functions supporting the roles of PMS, and 3) data conditions supporting the PMS functions. Therefore, it can be said that data conditions govern the overall PMS development scheme. If road agencies cannot satisfy the data requirements of their desired PMS, it is imperative that they change their scheme, unless they make alternate plans for data acquisition. However, if a PMS manager suggests a data inspection plan on unnecessary data content in the current PMS, road administrators may (properly) refuse the suggestion.

This is a foreseeable scenario. To continue the development plan uninterrupted, road agencies need to envision preconditions in advance. Because it is already too late when road agencies realize certain data were essential, they should have not only comprehensive understanding of their current situation but also sufficient knowledge of the overall PMS.

The second consideration is "Who develops the PMS?" Regarding this issue, this paper compares two concepts: "One size fits all" and "One finds one's own size." The former concept, whereby everyone wears same-sized, or "free-size" clothing, could be compared to the HDM-4 (Highway Development and Management-4) model developed by the World Bank, which tries to push all users under one sufficiently large umbrella (that is, one with enough PMS functions). On the contrary, the latter concept, whereby individuals seek their own sizes, emphasizes having sufficient skills to satisfy particular demands. To use an analogy, based upon demands and skill, fabric can be made not only into apparel but also into various other items such as bags or curtains. Note that sustainable development is attainable when a road agency has sufficient capacity for self-development. Therefore, implementation of ready-made software is not recommended. Even if ready-made software guarantees much cheaper and easier application, it should be excluded from the alternatives for the future because ready-made software is usually a unilaterally developed "black box" that hides all system resources and does not allow any modification. If necessary, it is recommended that such software be applied as an external model for special demands, such as comparison with domestic models, and for research purposes.

In the previous paragraph, the self-development strategy is described as the best solution. However, some may point out its difficulties due to a lack of data, budget, time, technology, and even interest in the Asset Management System (AMS), especially in developing countries. The second-best alternative may be the universal application of an international standard. However, it has been revealed that a unilaterally developed PMS model cannot satisfy various unknown users. As a third-best alternative, this paper suggests development of the "Open-source Hybrid type PMS model," combining the strengths of the two alternatives. The Hybrid PMS could be defined as *"A total system having easily customizable system architecture including database, PMS cycle management functions, pavement deterioration forecasting models with LCCA model to satisfy users' various objectives and heterogeneous PMS situations.* Its properties would be 1) rich contents, 2) ease and self-customization, 3) free software, 4) flexibility and 5) open-source. It would be especially useful in developing countries until they have the capability for self-development. Furthermore, it can serve as a means of communication among road agencies seeking a multilateral international standard. Nevertheless, self-development is still the ideal solution that must be pursued by every road agency.

4. DEFINITION OF PMS CAPABILITY LEVELS

While the purpose of what we have termed "PMS" may be similar among organizations—to facilitate maintenance work and to enhance cost-effectiveness amidst budget constraints—the PMS of each road agency usually differs from others in system framework, components, functions, and even definitions of the same content. In fact, it is difficult clearly to define the term PMS because each road agency has a different image based on its own current system. Regarding this issue, this paper aims clearly to define the term according to PMS capability levels, the most fundamental standard affecting other criteria.

The general objectives of PMS development could be divided into the initial introduction of PMS, the domestication of the introduced PMS model, or the improvement of current PMS capabilities. Properly, the demands occur successively, beginning with the initial implementation. Road agencies may have different distances between two points indicating the current and desired level of PMS capability. Although the distances differ, agencies' efforts are focused on progressing toward the desired PMS from their current PMS. This implies that PMS development has direction, and the development strategy also should have a formal (or general) direction based on the stream of improvement of PMS capabilities. Therefore, establishing evaluation standards for various PMS situations and leading them in the best direction must be the main considerations when PMS capability levels are defined.

For this purpose, this paper suggests *"Stepwise Directional Customization Approach (SDCA)"* defined as *"A formal (or the best) direction of development of PMS considering user's current and desired PMS capabilities level"*. With well-designed standards regarding the data level, required function, PMS components and their results, users can incorporate successive steps into long-term development plans for their PMS. This is well matched with the concept of sustainable development. The basic development strategy, the SDCA, could have three important benefits: 1) assessing the current PMS situation by standardized index, 2) showing the best development scheme with regard to any PMS situation, and last 3) getting every country on track toward PMS development (*i.e.* toward having compatibility with others). The step indices could be used as indicators characterizing the PMS situations of each country. If many countries follow the steps, the indicator could be an international standard for evaluating and comparing management capabilities. The SDCA is comprised of 2 phases divided into 5 general stages and 2 mature stages as follows:

General stage A: Expert system dependent level A - Without data and system: At this stage, there is no data, no system, or even any interest in maintenance and management. The agency does not conduct inspection work to check pavement conditions and inventory data. Decisions for maintenance are made in a very reactive manner based on the experience of road managers during poorly conducted patrols.

General stage B: Expert system dependent level B – With (incomplete and limited) data: Some inventory and condition data are available. However, the data are not vividly applied for systematic decision making processes due to the lack of a long-term PMS development plan. Moreover, incomplete or limited data make the situation unstable. Decisions for maintenance at this stage also follow the expert system in a reactionary way. At this level, usually the "Worst-First" strategy is used for decision making, taking into consideration budget limitations.

General stage C: Database dependent level: This is the most typical level of PMS. Road agencies at this level operate a procedural pavement maintenance cycle, and have a reasonable dataset to support maintenance work and budget estimation. In brief, this is an agency-oriented level (or PMS cycle-oriented level) focused on maintenance work only. Since at this level there is a basic framework for pavement management, there is the potential for increasing management efficiency with minimal effort. However, it is unknown to agencies at this level whether or not their current strategy is optimal, and they may be eager to enhance cost-effectiveness by optimizing their PMS strategy.

General stage D: Modeling level A – Pavement deterioration forecasting models: This is also one of the typical types of PMS. The pavement deterioration forecasting model (hereinafter, deterioration model) should be the first step in modeling for PMS because it is the foundation of every PMS analysis. At this level, a road agency can conduct various pavement performance analyses and simplified economic analysis by the What-if analysis. This stage is attainable to agencies with enough performance history (or time-series) and inventory data. This level may have higher cost-effectiveness because data demand could be minimized for long-term economic analysis. However, the definition of LCC at this level has limitative meaning that considers only road agency cost. Although road agency cost is the most important factor in the decision making process, this might be incomplete information because it is road agency-oriented information.

General stage E: Modeling level B – Full life cycle cost analysis model with optimization procedure: Stage E could be considered the maximum level of PMS capabilities. At this stage, much comprehensive information on the socio-environmental cost incurred by road investment is used in the decision making process with budget optimization procedures. The life cycle cost at this level could be considered as (a part of) total transport cost because it assumes that most costs occur when road users are on road sections. As objective functions of the optimization, minimizing NPV or maximizing condition recovery can be applied. This stage is realized by compiling detailed life cycle cost contents and optimization procedures at stage D. Since the additional life cycle cost contents consider vehicle operating cost (fuel, tires, engine oil, vehicle maintenance and depreciation cost), travel time cost, accident cost, work-zone effects, and emission costs, various and meaningful information can be used in decision making. Although the PMS model in stage E can produce a great deal of powerful and interesting information, there are not many cases manifesting this level because it requires a considerable number of sub-models, a huge amount of data, and specification data (*e.g.* vehicle characteristics, accident rate, various unit costs, etc.). To maintain this level, additional budget resources for PMS application are required for inspection and Research and Development (R&D) projects.

Mature stage F: Feedback / Improvement / Customization phase: After each user reaches its desired stage (not necessarily stage E), road agencies must jump to this stage. Though the PMS physically reaches the desired level, the PMS needs feedback, improvement and customization in a continuous manner to satisfy heterogeneous environments. The main efforts would be 1) improving or modifying pavement deterioration models following data accumulation, 2) elaborating on or simplifying the life cycle cost analysis model, 3) eliminating useless items of the current PMS, or adding useful items from another stage, 4) modifying current components and structures for special demands (*e.g.* changing the database to a visualized DB, web-based PMS operating system) and 5) developing unique functions for special purposes (*e.g.* Hidden Markov for measurement error[9], and local mixture hazard model[10] for defining heterogeneity of deterioration speed among road groups.

Mature stage G: Specification / Documentation / Legislation: When enough feedback and improvement have occurred, core standards for pavement maintenance and management can be specified, documented and legislated. The results serve as official guidelines at the national level, facilitating decision making with regard to every PMS activity. This is the ultimate goal of PMS. Main contents to be specified are 1) surface and basement materials, 2) pavement design method (*e.g.* thickness of each layer), 3) engineering method of construction and maintenance, 4) definition of data requirements, 5) specifications of inspection work regarding interval, contents, and methods, 6) definition of economic analysis method (LCC contents and estimation models), 7) pavement deterioration forecasting models, and 8) decision making process defining mandatory analysis work.

The stages are not separate, but are in a hierarchical relationship in the best direction. In brief, the order of the stages shows implementation or improvement steps. The relationships of the 7 stages are described in **Fig. 1** and **Table 1**.

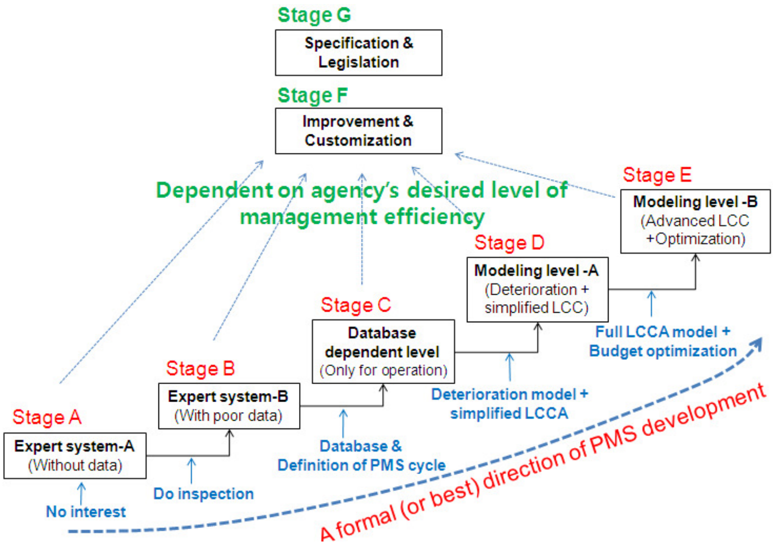

Fig. 1 Suggestion of development steps of PMS by the SDCA

Table 1 Description of PMS capability levels

Capabilities	Descriptions	Requirements to advance to next state	Main functions of PMS (Capability of PMS)	Additional system components	Core data
Stage A	· Expert system dependent level without data	· Inspections for pavement condition & inventory data	· No function and system	· N/A	· N/A
Stage B	· Expert system dependent level with (incomplete) data	· Database + definition of PMS cycle and activities · Securing general data requirement in PMS	(For a PMS cycle) · Maintenance schedule · Inspection schedule · Budget estimation	· Data tables	· Pavement condition indices · Minimized inventory data
Stage C	· Database dependent level or PMS cycle-oriented level	· Pavement deterioration forecasting model(s) · LCC model for agency cost	(For a PMS cycle) · Overall PMS activities plan · Basic database functions · Support external models · Data error processing · Maintenance design · Budget estimation	· Database · Internal PMS model · External PMS model (if necessary)	· Additional data to be general dataset · Unit costs by maintenance types
Stage D	· Modeling level A - Pavement deterioration forecasting model (Performance analysis + estimation of agency cost)	· Full LCCA models · Optimization functions	(During analysis period) · Performance analysis · Comparison of maintenance strategies · Economic analysis on agency cost · Accounting function	· Forecasting model · Functions estimating road agency cost	· Enough time-series performance data · Explanatory PMS variables
Stage E	· Modeling level B – LCC (road user and socio-environmental cost +optimization)	· Domestication · Customization · Elaboration	· Economic analysis with additional LCC contents · Optimization functions which maximize NPV or condition recovery	· LCC models · Optimization functions	· LCC related data · Unit costs for additional LCC contents · Model coefficients
Stage F	· Feedback level	· Continues feedback	· Feedback, improvement, and customization of current PMS	· Case by case	· Case by case
Stage G	· Specification, documentation and legislation level	· Ultimate stage but needs continuous feedback corresponding with demands	· Documentation & application to real field work	· Case by case	· Case by case

When road agencies attempt initial implementation of the PMS, they can define a suitable stage by referring to the PMS functions and data requirements of each stage. The desired level need not be the maximum capability (*i.e.* stage E) but should be chosen according to agencies' environments and objectives. A road agency can choose as its desired PMS level a lower stage if that agency faces current budget or technical limitations, later adjusting its level in accordance with its increased capability. In the case where a current PMS system is improved, pre-conditions of previous levels should be fully institutionalized as the system reaches a more advanced stage. It is suspected that many countries have been skipping important procedures and missing critical points at previous stages. If a current PMS does not satisfy the preconditions of previous stages, the model must return to those previous stages to achieve sustainable development. Thus, in order to define their desired level of PMS, road agencies would need key information about what qualifications must be met at each stage before advancement to the next PMS level.

As would be expected, because all criteria are based on the definition of PMS capability levels, that definition is the focus of this paper. While certain details in **Table 1** can be revised and improved in the future, the basic concepts for PMS evaluation will remain fixed.

5. DEFINITION OF PMS FUNCTIONS BY PMS CAPABILITIES

There are many functions that facilitate PMS operations and analysis. This paper attempts to classify general functions by PMS capability levels. By determining suitable PMS capability levels, road agencies can provide important information that would create links with PMS framework and data requirements. General functions have been subjectively classified into 6 categories according to the main roles of PMS, and level of importance. The definitions are presented in **Table 2**.

In **Table 2**, the PMS functions are classified first according to data requirements, database, management, pavement deterioration forecasting, economic analysis and accounting function. Then, the functions are once more subdivided according to the level of demand.

Users may choose reasonable functions to build their customized PMS model by considering their data conditions and objectives. It is recommended that a suitable level be determined by observing the horizontal axis (from bottom to top) of **Table 2**, which is related to the main roles of PMS (or PMS capability level), and then checking the vertical axis (from left to right) to find a suitable level of functions. The main considerations regarding the use of this procedure would be 1) to decide whether or not to include PMS analysis procedures (*i.e.* pavement deterioration model, economic analysis and optimization), 2) to define the scope of LCC (road agency cost only VS. adding various LCC contents), 3) to determine whether data are sufficient to cover the desired PMS functions and lastly, 4) to see if there is a hierarchical relationship among the functions. For example, long-term economic analysis is not available without the pavement deterioration forecasting function.

The data requirement becomes totally different according to the definition of desired functions and their properties (*i.e.* estimation methods). For that reason, the data requirement should be defined at the last stage after all other details are defined. Taking into account the results of the data definition, road agencies must establish additional strategies regarding data inspection. This will be discussed in detail in **Chapter 6**.

The database is a tool for saving all historical data, and it should have general database functions, such as searching, deleting, modifying and exporting. To facilitate daily or annual activities of the road agency, reporting functions that show a summary of network conditions and simple statistics are recommended. A function supporting internal or external models is recommended for direct and easy applications. Since such functions could change the database structure due to the normalization procedure of data tables, these functions should be considered from the outset. Because layers of data can be easily managed in the GIS system, a visualized database at the advanced level is useful in cases where road agencies must manage various road related facilities. Sometimes, developing web-based systems or linking with other road related systems can aid the practical operation of PMS between headquarters and branch offices. Note that designing a database demands more time than expected so as to take into consideration the wide range of factors related to PMS operation, analysis and even relationships among systems.

As main functions for PMS cycle management, this paper suggests 1) the estimation of work demands on inspection and maintenance, 2) work design, 3) work effect, 4) error processing, 5) budget estimation and reporting function, and 6) near-optimization procedure during a PMS cycle. These functions can be inserted as part of the current PMS cycle, if necessary. The management function should be paired with the database because it has a close relationship with database updates. These paired functions are minimum requirements for PMS operation.

The pavement deterioration forecasting function is a core element for economic or performance analysis. So far, many theories and models with different properties have been developed for various purposes [9)-20)]. The models can be divided into deterministic and stochastic, or empirical and mechanistic. Although stochastic models are preferred over deterministic models due to uncertainty about the pavement deterioration process, their applications are not for everyone. Since pavement deterioration forecasting is totally dependent upon the historical performance data affected by many kinds of PMS variables, there are many limitations to establishing the forecasting models, especially for road agencies in the beginning stage of PMS. In the case of the initial implementation of PMS, road agencies may have to apply mechanistic models like HDM-4, or apply another's forecasting functions. However, road agencies can update their models based on the Bayesian concept as data accumulates. In the long run, the road agency will have the capability of developing its own customized deterioration forecasting functions. One important consideration regarding properties of the forecasting model is whether it can satisfy objectives, and whether it can be satisfied by the data conditions of road agencies.

The main role of the pavement deterioration model is to show the performance of road pavements. To extract meaningful information for various purposes, an economic analysis based on pavement performance and investment level is essential. In general, economic analysis in the PMS sector follows the concept of LCC to enhance budget cost-effectiveness. In the economic analysis, cost streams by user-specified alternatives are empirically simulated, and various economic decision criteria are estimated to help in decision making. For this procedure, most road agencies have focused only on the agency cost. However, the analysis has the weakness of not taking into account the entire LCC affected by the road investment level. According to reviews of the definition of LCC contents in the PMS sector, the main contents were Vehicle Operating Costs (VOC), travel time costs, accident costs, and vehicle emission costs. Included as components of VOC were fuel consumption, tire wear, engine oil cost, vehicle maintenance cost, and vehicle depreciation cost [2),8),21)-27)]. In fact, the agency cost may account for a very small ratio of the total transport cost. Nevertheless, cases treating the advanced LCCA are not very common in reality because the money is invisible, and such cases demand too much data for their estimations. To consider only agency cost might be enough to satisfy general objectives in the practical operation of PMS. However, we must recognize that a revolution in PMS will not be the result of any change in application methods (*i.e.* management

Table 2 Definition of general PMS functions

Functions	Core level	Semi-core level	Recommended level	Advanced level	Available stage(s)
(Near) Optimization	・Optimization – I Work scheduling by user-specified priority ranking	・Optimization-II Maximizing condition recovery	・Optimization-III Maximizing NPV	・Optimization-IV Best maintenance strategy by long-term accounting concept	E, partially D
Economic analysis	・Minimized LCCA - I Maintenance cost only (by deterministic or stochastic approach)	・Minimized LCCA - II User-specified agency cost only (*e.g.* adding inspection cost)	・Simplified LCCA Agency cost + (user-specified) simplified road user cost	・Advanced LCCA Full road user costs and socio-environmental cost Accounting function	E, partially D
Pavement deterioration forecasting	・Deterministic - I Empirical-mechanistic model (for beginning stage only)	・Deterministic - II (*e.g.* single and multiple regression)	・Stochastic - I (*e.g.* Markov hazard model[11)])	・Stochastic – II (*e.g.* local mixture hazard[10)], hidden Markov chain[9)], etc.)	D, E
PMS cycle management	・Finding work demands (inspection & maintenance) ・Data error processing	・Work effect models ・Work design models ・Budget estimation	・Reporting function (summary of activities during a cycle)	・Near-optimization of agency cost (by changing current plan)	C, D, E
Database	・Basic database function ・Data exportation	・Reporting function (network condition, simple statistics)	・Support for internal and external models (*e.g.* HDM-4)	・Visualized database ・Web-based system ・Link with other road facilities or systems	
Data requirements	(For stage A and B) ・Identification ・Simplified inventory & condition data ・Unit costs for agency cost	(For stage C) ・General inventory that includes pavement condition indices and PMS variables	(For stage D) ・Enough time-series pavement condition ・(special) PMS variables	(For stage E) ・Detail data for LCC modeling ・Unit costs for socio-environmental cost ・Subsidiary data	A, B, C, D, E

strategy), but of many fundamental factors related to hardware, such as pavement material, design methods, etc. The advanced LCCA may be useful for research regarding these matters.

One strong recommendation is to acquire the accounting function, which could be a bridge between PMS managers and administrators, who have different viewpoints. This function provides accounting information to assess whether repair is sufficiently realized for maintaining the service level of road pavement[16]. The budget level, an important policy parameter, can be determined while maintaining the agency-specified pavement service level of the entire road network. This function allows PMS managers to show the importance of the budget directly to administrators and to make more persuasive cases for funding when long-term budget plans are drawn up. For a detailed description of accounting functions, see Kobayashi *et al.*[16].

The last component is the (Near) optimization function for maximizing the cost-effectiveness of a constrained budget. This function finds the best maintenance alternative based on budget limitations, and would be useful for defining better maintenance criteria under a specific budget level. Optimization principals can be classified as maximizing NPV (Net Present Value) or maximizing condition recovery. This function can determine the best maintenance strategy based on the long-term accounting concept. Moreover, the solution can be applied at the individual section level, as well as at the network level. In brief, every individual section could have a different optimal maintenance standard based on deterioration speed and LCC scale. Note that the term, 'Optimization' is, strictly speaking, incorrect. A more appropriate expression might be "Near-optimization," which more accurately conveys the idea that the optimized solution means the best alternative among applied alternatives in the simulation.

6. DATA REQUIREMENTS AND MANAGEMENT

This chapter should be highlighted as the most important of this paper. The matter of data governs the overall development plan, as well as every detail of the estimation models. Most road agencies have a deep interest in this issue because it is directly linked to the volume of PMS work and to budget requirements. While we treat data content (or requirements) as an important issue, we also wish to focus on the additional issue of data management. To avoid failures in data policy, it is necessary to have a deep understanding of these two issues.

(1) Data management

According to lessons learned from past failures, strategic data management is the key to successful PMS operation and development. In some cases, due to poor management strategy, road agencies have had to discard valuable data, the loss of which costs a considerable amount of both money and time.

Among the many issues related to data management, this paper emphasizes identification (ID) management. Simply, the ID involves units of data saving. In the PMS sector, we often use the term "Section." However, its definition has a very close relationship with pavement maintenance and data management. In many countries, it is common for road agencies to have section units pre-defined according to administrative, physical or operational characteristics, and these usually become the agencies' basic units for data saving. Road agencies conduct inspection work by dividing a section into many inspection units. In the end, the inspection units are integrated to obtain pavement condition data for the section. Sometimes, several section units are further integrated as a homogeneous section unit, and the homogenous section unit has often been used for analysis work. Road agencies usually base maintenance work on the section unit. After maintenance work is conducted, data tables are updated to reflect the results. The most serious problem with this scheme is that partial maintenance may occur within a section because of the inability to reflect maintenance effects exactly, especially in cases involving a rehabilitation level of maintenance. An additional problem in reality is that the definition of the sections or of the homogenous section is often changed. Frequent changes in definition can cause an inverse condition whereby a road section is deemed to have improved even though no maintenance work has been done. This problem is considered one of the most serious in PMS data management, as it implies that previous data becomes obsolete and should be discarded. Experience has shown that road agencies must be careful when defining the basic unit of the PMS.

Identification rules could be based on inspection, maintenance or analysis. The ideal definition is, of course, conducting management and analysis work by using the inspection unit. Accordingly, it is necessary for the inspection unit to be short (maybe less than 100m) to reduce any bias due to partial deterioration and maintenance. However, such short units might be unrealistic or inefficient due to the size of the population, the preservation of homogeneity in pavement design, or coordination with administrative units. Therefore, applying multiple units is recommended. Of course, the management unit should be the center of units usually called "sections". For defining homogeneities of widely distributed sections in the network, it would also be useful to include grouping information about such matters as road class, pavement material, physical pavement design, traffic load level, and climate conditions. This could be considered as another identification rule useful for various research purposes, especially in showing significant explanatory variables in different PMS environments, and establishing better maintenance design standard considering PMS variables.

Vietnamese PMS is a worst-case scenario, with road officials saving their data according to different ID rules (even creating rules) with every inspection. For this reason, data cannot be linked as time-series data. Maintenance history cannot be properly or exactly reflected, one of the main reasons being that Vietnamese PMS is committed to HDM-4 application. Presently, the HDM-4 model is applied every fiscal year only to budget estimation. Since Vietnamese road managers are now applying the default pavement deterioration model inside the HDM-4 model, there has been no need to build time-series data for calibration of the deterioration model. In brief, road managers have been discarding previous inspection data. Recently, they have realized the many limitations of the unaltered HDM-4 model and have become interested in developing a customized PMS. However, there is a lack of time-series data, essential for building the forecasting function. Meanwhile, for the past 10 years, the Vietnamese have invested enormous budget resources in acquiring rich data contents for HDM-4 application, data that nevertheless cannot be used to create a customized PMS. This unfortunate case well describes the importance of data management.

Another issue related to the data management scheme is inspection strategy, the first concern about which is interval. In most cases, a 3-4 year interval has been chosen as the frequency at which inspection should be conducted for accumulating data and finding maintenance objects. However, the inspection interval determines the quantity of additional deterioration (over maintenance criteria), which significantly affects road users and the environment. Depending on the results of maintenance retardation, a change in maintenance design might become necessary, resulting in worse cost-effectiveness than in the scheme originally established by the road agency. Since road agencies cannot conduct maintenance work unless they find that the road condition meets their maintenance criteria, actual maintenance criteria in reality are determined by the combination of "official maintenance criteria" and "delays in maintenance" generated by the function of pavement deterioration speed, inspection interval, and budget limitations. Sensibly, the network having a faster deterioration speed needs to apply a shorter inspection interval to minimize the quantity of deterioration. With economic analysis, the optimal inspection interval in relation to deterioration speed can be determined.

The second concern is about the long-term inspection scheme. Simply put, the question is whether the inspection work of an entire network should be conducted all at once or divided over several years (*i.e.* inspection interval). The properties of PMS data may change according to which type of inspection scheme is used. Accordingly, the type of inspection scheme has significant effects on actual maintenance plans, as well as on PMS research.

(2) Data requirements

Data requirements cannot be defined before fixing all other types of details related to PMS. Even if this paper were subjectively to suggest a pre-defined dataset based on a specific PMS situation, such a dataset would not be suited to various PMS situations. For that reason, it is necessary that data requirements for each PMS be determined by individual road agencies, taking into account the following three factors: 1) the desired level of PMS capability, 2) the external or internal PMS model in use, and 3) domestication procedures (see **Fig. 2**).

Since factors 2) and 3) are heterogeneous factors particular to each road agency, this chapter will discuss data requirements based on the desired PMS capability level. To define the data requirements, data categories should firstly be defined. The general categories and main data are summarized in **Table 3**. With the definition of the categories, this paper suggests 4 pre-defined datasets supporting each PMS capability level respectively, a simple summary of which can be found in **Table 4**.

The minimized dataset is to support stages A and B, which follow the "Expert system" based on the concept of a "Worst-first" maintenance strategy. The general functions of this level are defined as estimating maintenance and inspection work, and the required budget during a PMS cycle. For the two functions, the following data summarized in **Table 5** are adequate to satisfy the data requirements of stages A and B.

The general dataset is to support stage C, a database-dependent level at which the tactical "Plan-Do-See" management cycle is conducted. Distinguishing it from the minimum set, the general dataset has traffic related data, general pavement deterioration indices, pavement design variables, maintenance and inspection history, records of PMS activities during a cycle, and much detailed subsidiary data. **Table 6** summarizes the contents.

Table 3 General categories and main data

Classification	Description	Main data
Identification	· Definition of road networks by agency, network, link (homogeneous section), section, and inspection unit.	· Identified by -Analysis unit, Management unit, Inspection unit
Physical and operational road characteristics	· Describing physical characteristics of road sections required for budget estimation, and forecasting pavement deterioration · Describing operational road characteristic	· Section length (km) · Carriageway width (m), number of lanes · Slope (%), curvature (degree/km) · Type of road (*e.g.* bridge, tunnel,) · Speed limit (km/h) (for advanced LCCA only)
Pavement design variables	· Describing details of the pavement design affecting pavement strength and maintenance work	· Pavement materials · Thickness of each layer (mm)
Maintenance & inspection history	· Recording all maintenance and inspection histories with age indicators****	· History of (re)construction, rehabilitation, repair, routine maintenance, and inspection
Explanatory variables	· Significant PMS variables that affect pavement deterioration speed, and M,R&R activities (could differ with each road agency)	· Traffic: AADT*, vehicle composition (%) · Climate conditions: Temperature (C^o), rainfall (mm/yr) etc. · Etc.
Pavement condition data	· Various deterioration indices that characterize pavement conditions	· Minimum: crack (%), rutting (mm), IRI (m/km), and pothole (n/km) · Optional: types of crack, raveling area (%), edge break (m^2/km), texture depth (mm), skid resistance (SCRIM 50km/h)
Vehicle characteristics	· Describing properties of vehicle types in use	· Size, num. of wheels, axles, and tires, fuel type · PCSE**, ESALF*** · Unit costs for LCCA
Subsidiary data	· Subsidiary data to conduct performance and economic analysis	· Interest, model coefficients, unit costs and so on.

*Note: *AADT (Annual Average Daily Traffic)*
*** PCSE (Passenger Car Space Equivalent factor)*
**** ESALF (Equivalent Single Axle Loads Factor)*
***** AGE0 ~ AGE4 (0 = inspection, 1 = preventive level, 2 = repair level, 3 = rehabilitation level, 4 = construction level)*

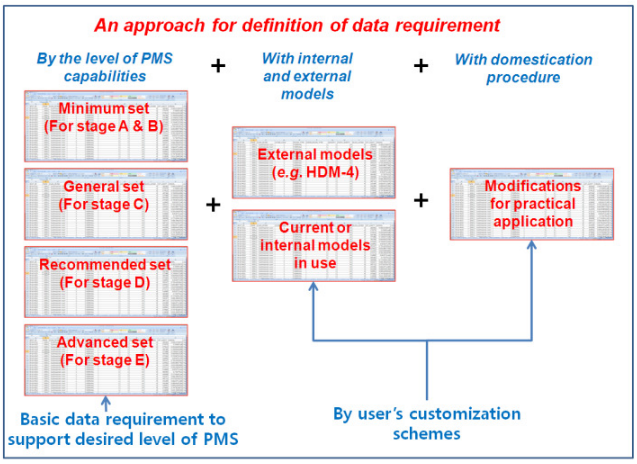

Fig. 2 Definition of data requirement in PMS

Table 4 Definition of datasets based on PMS capabilities

Definition	PMS stages	Description	Data requirement
Dataset A	All stages	***Minimum level*** to support the "Expert system" that follows "Worst-first" concept of maintenance strategy	· Identification · Minimum level of physical road characteristic · Pavement conditions · Core subsidiary data
Dataset B	C, D, E	***General level*** to support "database dependent level" for typical PMS operation	· General inventory data to support operation of a PMS cycle
Dataset C	D, E	***Recommended level*** to support "Modeling level-A" that estimates pavement deterioration and agency cost	· Sufficient time-series pavement related data for establishing pavement deterioration functions · Enhancing special considerations (*e.g.* climate factors)
Dataset D	E	***Advanced level*** to support "Modeling level-B" that applies advanced level of LCCA and optimization for decision	· Sufficient inventory data for application of road user and socio-environmental cost

Table 5 Data requirements of the minimum level

Classification	Contents
Identification	ID (saved by inspection, maintenance, or analysis unit), location information
Pavement condition indices	User-specified condition indices for maintenance work of agency
Physical road characteristics	Section length, number of lanes, width of lanes
Subsidiary data	Unit costs of maintenance types and inspection

Table 6 Additional data contents at the general level

Classification	Contents
Traffic data	Traffic volume in AADT, composition ratio
General pavement condition indices	Cracks, rutting, IRI, Pothole (or more, if necessary)
Pavement design variables	Current pavement type, surface material, thickness of each layer,
Maintenance and inspection history	Conducted year (and elapsed time), details of conducted maintenance work
PMS activities	Record of conducted (and delayed) maintenance and inspection as planned Executed budget of each activity
Additional subsidiary data (or information)	Detailed unit costs related to pavement design, ESALF of each vehicle type, maintenance criteria, error processing mechanism, maintenance codes

Note that the "General pavement condition indices" in **Table 6** are for bituminous pavement. If the desired PMS of a road agency aims to treat additional pavement materials, the dataset should have additional indices corresponding with the materials. The "Current pavement type" is for characterizing properties of base and surface layers. The index considers the history of previous maintenance work in order to facilitate the practical design of maintenance[18),28)]. The "Maintenance codes" item is an optional requirement for designing maintenance work determined by PMS variables (*e.g.* traffic volume, temperature, road class), and may be quite helpful in the design of objective maintenance. However, establishing such standards requires an enormous quantity of data, as well as time, and is an impossible goal without a strategic PMS development plan.

The general dataset provides most data necessary for PMS operation. Besides, many kinds of useful data can be estimated (or calculated) from the dataset, such as pavement strength characterized by SNP (Structural Number of Pavement), and traffic road level expressed by MESAL (Million Equivalent Single Axles Load). Since the general dataset contains minimum data for the general level of PMS, it could be called a separate level of minimum dataset.

Although the general dataset can support the basic framework of PMS, it cannot be considered the recommended dataset, which ideally should have additional PMS variables to be used in the modeling of the pavement deterioration process. In brief, the recommended dataset is defined as a combination of the "general dataset + user-specified PMS variables". The determination of user-specified PMS variables should reflect significant factors that affect pavement deterioration speed or practical PMS operation. Significant variables may differ in type with each road agency due to heterogeneous environments. For example, if there are many bridges and tunnels in the network due to mountainous topography, it is necessary to strengthen data contents about the objects. In cases where road networks are spread over huge areas with various climate conditions, climate data could be considered a significant factor affecting deterioration speed. In brief, user-specified PMS variables are for establishing better maintenance or management strategies with regard to the unique PMS situations of each road agency. Since the general dataset has most of the important data, improvement from the general level to the recommended level would not be very difficult in most cases and would depend to a large extent on the interest and capability of the PMS manager.

Although datasets A, B and C can support the estimation of road agency costs, they may be inadequate for conducting advanced level LCCA, which includes various LCC contents. Estimation regarding road users and socio-environmental cost has usually followed deterministic methods based on an empirical and mechanistic approach. This implies that estimation models are composed of many model coefficients developed under specific road conditions (or countries). Road agencies will be able to use the default model as it is. However, obtaining reliable estimation results often requires model calibrations. For advanced LCCA, many subsidiary data and standards to support estimation models should be prepared. Even if the advanced level of dataset has many benefits, its cost-effectiveness is still questionable, as this level requires huge research efforts to develop customized models, to find model coefficients, or to establish standards. For this reason, there are few cases that apply the advanced LCCA. Since the advanced dataset is totally dependent on the LCC contents and their estimation models, we are unable to give detailed descriptions in this paper. Regarding estimation models on road users and socio-environmental cost, refer to Bennett and Greenwood[29)] for an example.

7. GENERAL FRAMEWORK OF PMS CAPABILITY LEVEL

So far, PMS capability level, PMS functions, and data requirements have been discussed. Based on the contents, a PMS framework can be established according to PMS capability level, summarized in **Table 7** and **Fig. 3**. Note that **Table 7** and **Fig. 3** could be reorganized (or customized) according to a user-specified PMS development plan at a system level as well as at a functional level.

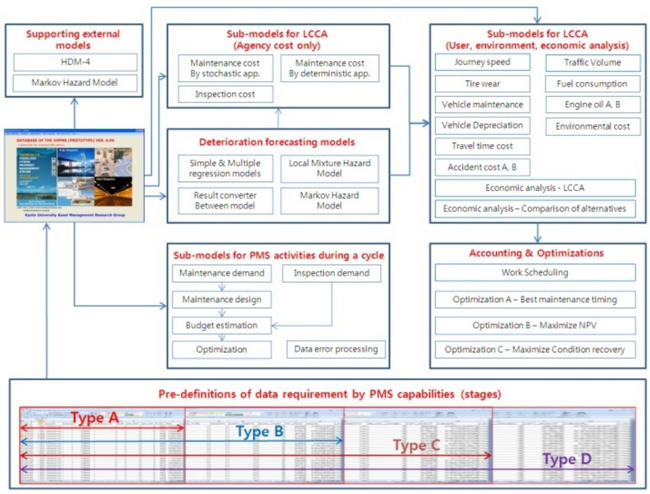

Fig. 3 Suggested general framework of PMS

Table 7 Summary of PMS components

Categories	Roles of PMS	Roles (name) of components	Description	Level of demand
Data definition	Data management	Core set	Identification, simplified inventory & condition data, unit costs for maintenance	Core
		Semi-core set	General level of inventory & condition data	Recommended
		Recommended set	Enough time-series data + user-specified PMS variables	Recommended
		Advanced set	Detailed data for establishing advanced LCC models, subsidiary data and rich grouping information	Optional
Database		Integrated database	Database based on user-specified data definition and database functions	Core
Management	Operation of PMS cycle	Maintenance demands	Determining maintenance demands by maintenance types	Core
		Inspection demands	Determining inspection demands by inspection types	Optional
		Data error processing	Determining data errors, and processing them by user-specified algorithms	Core
		Maintenance design	Deciding suitable maintenance codes corresponding with levels of PMS variable	Recommended
		Budget estimation	Estimating budget requirements of agency-specified maintenance alternatives	Core
		Near optimization	Determining better work schedules by controlling current management schemes under budget constraints	Recommended
Deterioration forecasting	Performance analysis	Empirical-mechanistic models	Ready-made deterioration models developed by laboratory experiments or specific field data.(*e.g.* deterioration models in ready-made software)	Not recommended
		Simplest models	Deterioration models that can be established with minimum data (*e.g.* single or multiple regression)	Core
		Advanced models – General	Deterioration models that provide critical information for pavement management based upon the stochastic approach (*e.g.* Markov chain, hazard models[11])	Recommended
		Advanced models – Special	Deterioration models for special issues on pavement management (*e.g.* hidden Markov chain[9], local mixture hazard[10].	Optional
LCCA model	Economic analysis	Maintenance cost	The portion of agency cost for maintenance work that can be estimated by a deterministic or probabilistic approach	Core
		Inspection cost	The portion of agency cost for inspection that can be estimated by inspection rules (depending on the definition of road agency cost)	Optional
		Travel time cost	Option 1: Estimating total travel time cost Option 2: Estimating additional travel time cost due to work zone	Optional
		Vehicle Operating Cost (VOC)	Option 1: Estimating the total VOC (composed of fuel, tire, engine oil, vehicle maintenance and vehicle depreciation) Option 2: Estimating additional VOC due to work zone	Optional
		Accident cost	Option 1: Applying the hazard exposure based method Option 2: Applying the pavement condition based method	Optional
		Environmental cost	Economic evaluation of substances from vehicle emission (The substances: HC, CO, CO2, NOx, SO2, Pb, and PM)	Optional
		Sub-models	Sub-models to support the advanced LCCA (*e.g.* traffic volume generation method, vehicle speed model, etc.)	Optional
		LCCA-cost stream	Estimating the cost stream of each analysis year including interest	Core
		Decision criteria	Estimating economic decision criteria (*e.g.* NPV, IRR, NPV/Cost ratio, and EUAC)	Recommended
		Sub-models	Traffic volume generation, Vehicle speed model	Optional
		Accounting function	Providing accounting information (*i.e.* budget level) to maintain a specific service level with minimized LCC	Recommended
Optimization		Work scheduling	Summarizing the work schedule through priority ranking	Optional
		Optimization	Determining the optimal work schedule which maximizes objective functions (*e.g.* NPV or condition recovery) under budget constraints, or finding the optimal budget under accounting concepts	Optional

The core information of this paper is embodied in **Table 7**, where functions are classified according to the level at which they are recommended. Selection of functions depends on road agencies' development schemes, and it should be noted that road agencies can increase their PMS capability in the future.

8. ESTABLISHMENT OF A DEVELOPMENT SCHEME

To establish a development scheme, the first procedure should be to gain a clear grasp of the characteristics of a country's PMS, and to define the desired level of its PMS. Road agencies must have sufficient time for this procedure. Basically, a road agency must first define "What we have to do," which depends on the difference between the desired and the current level of PMS. Note that differences should be checked not only forward but also backward for sustainable development. To draw a blueprint for the desired level, road agencies must check the current situation and roles of PMS from various viewpoints, which we classify into three: the system, function, and programming level.

The system level concerns "What the desired PMS can do" that determines the overall system framework and components. Of course, this question is contingent upon the PMS's main roles, which are divided into three categories: 1) data management, 2) management of the PMS cycle, and 3) PMS analysis. Afterward, detailed functions fulfilling selected roles should be specified (see **Table 2** and **Table 7**). If the suggested functions in this paper are insufficient to satisfy the demands of the desired PMS, road agencies must develop new functions at this level. As noted in **Chapter 5**, road agencies must check subordinate relationships among the functions. After identifying the system level, PMS functions, the overall framework, and physical system components are determined.

At the functional level, selected functions at the system level should be designed in detail, taking into consideration factors shown in **Table 8**.

At the programming level, all details should be addressed. For example, the main tasks at this level include determining kinds of programming language, determining system interfaces, and elaborating on or simplifying estimation models, all of which may depend on the particular tastes of road agencies and their PMS situations.

Table 8 Considerations for PMS development at functional levels

Contents	Description
Data definition	･Following the general definition in the PMS sector (*e.g.* definition of contents, unit, estimation method) ･Supporting all desired PMS functions as well as future demands. However, it is recommended that the general data requirements defined in **Tables 5** and **6** be fulfilled
Database	･Considering database type (*e.g.* texted or visualized) ･Defining detailed database functions reflecting demands of actual users so that the database can directly help annual, monthly and daily activities of PMS managers ･Considering special usages, such as supporting ready-made software or internal models
PMS cycle	･Reorganizing overall procedure by adding useful procedures or eliminating useless procedures
Deterioration models	･Defining type of forecasting method by considering actual application and data conditions (*e.g.* deterministic *vs.* stochastic, annual basis *vs.* state basis, or network basis *vs.* section basis)
Economic analysis	･Defining type of results, LCC scope, estimation methods on individual LCC contents, economic decisions criteria, and optimization methods
Heterogeneous factors	･Special considerations due to heterogeneous PMS situations of individual road agencies (*e.g.* integrating other road facilities or systems into one system, meeting demands of web-based systems, generating special reports)

9. APPLICATION OF THE CRITERIA TO DIFFERENT PMS SITUATIONS

This chapter presents simple case studies on establishing PMS development plans at the system level. Selected pilot countries Korea, Japan and Vietnam have different PMS histories (past), current PMS situations (present), and desired levels of PMS capability (future). The development schemes in this paper have been subjectively established by field experience, information on current situations, and data conditions from each country. However, the cases presented in this paper cannot be considered representative of each country.

Korea, a semi-developed country in Asia, has pavement management systems for national highways, expressways, and airports, among which the PMS for the national highway (hereinafter, Korean PMS) has been selected as a target for study. The Korean PMS conducts most of its activities according to self-developed standards and procedures. And while essential data is obtained through the system, Korean PMS has no pavement deterioration forecasting model or LCCA procedures, the main consideration being only the operation of the PMS cycle with a database. The Korean PMS is a typical example of the *"Stage C: Database dependent level"* as defined in Chapter 4, with database functions reliable for data management and simplified statistics. One special feature is that the HDM-4 is applied as an external model for prioritizing maintenance work.

Vietnam, a developing country in Southeast Asia, so far has no expressway (under construction). Therefore, the national highway plays an important role in road transportation. PMS in Vietnam has a relatively short history, having been used only since 2001. During the past 10 years, the HDM-4 model has been applied with road inspections—in 2001, 2004 and 2007. Since the HDM-4 application was legalized several years ago, PMS has been focused exclusively on the use of this model. In fact, Vietnamese PMS is in chaos due to the inadequate implementation of ready-made software. In a strict sense, the Vietnamese system, which mandates only data collection and the application of HDM-4 for budget estimation, is somewhat removed from true PMS. HDM-4 is an analytical tool only for LCCA, not for practical pavement management, which requires database and PMS cycle management functions. In reality, maintenance work in Vietnam has been progressing only relative to the expert systems employed by individual local PMS managers. Even though Vietnamese PMS has a wide range of data contents to support HDM-4 application, data resources are not well applied to practical pavement management. Worst of all, the inspection data from 2001, 2004 and 2007 cannot be linked as a time-series dataset. Vietnam's is a typical story of failure caused by the lack of a sustainable PMS development strategy, and officials must now return to the first step of drawing up a blueprint for the future.

Japan is a developed country with adequate road and railway networks, and with a self-governing system where many different PMS models are used by individual administrative units. It is therefore difficult to identify a general PMS model representative of Japan. However, one Japanese trend is to pursue simplicity, effectiveness, and self-development. As a typical model, this paper has selected a PMS used in Mie prefecture. The number of data contents was less than for the other two countries, but the PMS capacity level was higher. It was available under a self-development strategy conducive to "Tailor made-sized" models. However, such a domesticated or customized system has the weakness that it is often not compatible with the systems of other countries. For example, the Japanese system has domestic standards not matched with international trends, such as the use of the MCI (Maintenance Control Index[30]) as the representative pavement condition index[16]. Though such country-specific standards work well for pavement management within Japan, it is necessary to follow international trends in PMS sectors for compatibility with other PMS models. The current PMS situations and improvement plans of the three countries are simply summarized in **Table 9**.

Table 9 A brief summary of the PMS development (improvement) plans of Korea, Vietnam and Japan

Contents		Korea	Vietnam	Japan
Manager		KICT*	VRA**	Mie prefecture
Management objects		National Highway	National Highway	Local roads
Network Level		National network	National network	Regional network
Main issue		Management	Construction	Management
Current PMS condition	Data condition	Recommended level	Advanced level but minimum level (due to incompleteness of data)	Recommended level
	Database	Visualized database	Text-based database (By RoSy Base)	Text-based database
	PMS cycle	Self-defined cycle	Expert systems by local managers	Self-defined cycle
	Pavement deterioration model	N/A	Mechanistic-Empirical model (Un-calibrated HDM-4)[18]	Simple regression
	Life cycle cost analysis	N/A, but partial application of HDM-4 for prioritization of maintenance works	Partial application of HDM-4 for estimating agency cost for every fiscal year	Road agency cost, simplified road user cost (VOC + travel time cost)
	Budget optimization	N/A	N/A	Accounting function
	Components of internal PMS	Database + Excel-based programs	RoSy Systems and HDM-4	PMAS[16]
	External models	HDM-4[7], and RealCOST[25]		N/A
Evaluation of current PMS capability level		Stage C: Database dependent level	Stage B: Expert system dependent level	Stage D: Modeling level – A
Desired PMS capability level		Stage E: Modeling level – B	First step = Stage C: Database dependent level Final = Stage D: Modeling level A	Stage F: Feedback / Improvement level
Main tasks for improvement		Introduction of advanced LCCA into current PMS	(For first step) Establishment of overall PMS development plan	・Revising data contents ・Elaboration of the current deterioration model
Sub-tasks for current PMS		・Development of LCC model ・Revising data contents ・Redesign of database function	・Self-evaluation of their PMS ・Fixing long-term development plan ・Definition of data requirement ・Rehabilitation of current PMS data ・Development of database	・Redefinition of data by international standard ・Adding (or changing) deterioration forecasting model by stochastic type
Special considerations		・Adding data extraction functions for HDM-4 and LCCA application into current database ・Linking with traffic monitoring system	・Integrating the other road facilities (*e.g.* guardrail, manholes, speed poles etc.) ・Enhancing data tables with information on climate factors and drainage systems	・Enhancing geometric information into current data ・Link with bridge and tunnel management system

*Note: * KICT (Korea Institute of Construction Technology)*
*** VRA (Vietnam Road Administration)*

This paper has evaluated the current PMS capability level of each country at the database dependent level (Korea), the expert system dependent level-B (Vietnam), and modeling level-A (Japan) respectively. As the desired PMS capability level, modeling level-B has been designated for the Korean PMS because national guidelines[8)] require the inclusion of a wide range of LCC contents. In the case of Vietnam, modeling level-A was assumed as the desired level. To reach this level, Vietnamese PMS should rehabilitate the overall structure and review every detail from the beginning. However, the Vietnamese capability level cannot jump to the desired level instantaneously but should go through stage C until enough pavement inventory data is accumulated. Integrating other road infrastructure into one system is strongly recommended, since the VRA has the duty of managing all road facilities simultaneously. In addition, it is recommended that as a special consideration, data tables be enhanced with information on climate factors and drainage systems because Vietnam is a vertically long country with varying climate conditions. The desired level of Japan has been assumed as the feedback/improvement level based on modeling level-A, as there are already self-developed models satisfying PMS conditions and objectives in Japan. For system improvement, tasks include the redefinition of data contents and the elaboration of current pavement deterioration forecasting models from the deterministic to the stochastic type. As special considerations, enhancing geometric information and linking with bridge and tunnel management systems are recommended because most road sections in Mie prefecture are in mountainous regions with many bridges and tunnels.

Perhaps anyone can easily devise a basic PMS development plan by considering the current and desired level of PMS. However, development plans would be imperfect and meaningless unless they take into account the heterogeneous situations of individual road agencies. Ready-made software cannot incorporate such important factors into the system. For this reason, self-development is essential for sustainable PMS development.

10. CONCLUSIONS

Although it should be established at the outset of PMS implementation, long-term PMS development strategy has often been neglected, and this oversight has led to confusion among road agencies when they try to implement, evaluate or improve their PMS. Perhaps road agencies would welcome guidelines that would foster the sustainable development of their PMS from inception to maturity. This paper suggests criteria for the PMS capability evaluation method, PMS functions, data requirements and management, and a general PMS framework corresponding with PMS capability level.

From the beginning, this paper has emphasized two vitally important philosophies—the importance of taking a long-term view and the importance of self-development—which should be understood by every PMS manager and even by road administrators.

The first criterion concerns the evaluation of PMS capability level and is the foundation of other criteria in this paper. Suggested capability levels comprise 2 phases divided into 5 general stages and 2 matured stages. The main basis for classification was the roles of PMS: data management, the operation of the PMS cycle, and PMS analysis work. Afterward, general PMS functions of each stage were standardized by functional categories and level of demands. Road agencies can use this information to customize PMS functions to satisfy their desired PMS.

One of the most important PMS issues discussed in this paper regards data requirements and management. For successful data management, this paper emphasized identification rules and inspection strategy, which have a relationship with practical pavement management, as well as with PMS research work. Concerning data requirements, this paper suggested a methodology for defining contents. To support each PMS capability level respectively, 4 pre-defined datasets classified into minimum, general, recommended and advanced level were suggested. By using the criteria so far suggested, a general PMS framework considering hierarchical (or sub-ordinate) relationships was easily established. And a brief summary of the PMS components has been provided.

Finally, this paper has attempted to establish PMS development plans for different PMS situations. As pilot countries, Korea, Vietnam, and Japan have been selected. By the application of suggested criteria, it was found that the PMS capabilities of these countries were at different stages and that their desired levels were also different. However, the main and sub-tasks required to reach their desired levels could be easily defined by the criteria. Along with the basic plan, this paper additionally considers special demands for individual agencies' heterogeneous environments and interests. In brief, a PMS development plan can be made by modifying the basic plan for the desired level according to the special needs of an individual agency.

The suggested criteria in this paper are insufficient to take into account all considerations for PMS development. In addition, there is a limitation to making detailed descriptions because the application of the criteria would be different in individual cases. However, the concepts and philosophies are expected to serve as useful guidelines for the initial introduction, self-examination, and the extension of PMS capabilities. While this guideline may contribute at the level of individual agencies, a much more important benefit of the suggested criteria would be the establishment of compatibility among PMS models. Road agencies applying the criteria would have (partial) PMS compatibility with others who were also following the criteria, a scenario that would mitigate heterogeneity among PMS models while allowing heterogeneity in PMS situations. Mitigating heterogeneity among PMS models can greatly benefit the PMS world. In addition, the criteria could serve as a foundation for research on various matters such as PMS databases, PMS cycle management, and life cycle cost analysis models.

A further research will be development of the Hybrid concept-based PMS model (discussed in the **Chapter 3**) that follows the suggested criterions. This kind of PMS model can give direct contributions to road agencies which do not have enough capability for self-development. Note that the self-development is the most important factor for sustainable PMS development.

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