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A PRACTICAL PROCESS TO INTRODUCE A CUSTOMIZED PAVEMENT MANAGEMENT SYSTEM IN VIETNAM

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This paper presents the history of the application of a pavement management system (PMS) in Vietnam and the background to the successful development of a new PMS system that was customized from the Kyoto Model[1),2)] to make it suitable for local application. In addition, we report on a scheme for road asset management with sustainable cooperation between Japan and Vietnam, realized through the support of the Japan International Cooperation Agency as well as the contributions of many Japanese researchers and experts over a long period of time. Numerous efforts, both personal voluntary-based and organizational-based, have been made to enable the adequate transfer of technologies and knowledge, and to ensure that the capacity for road asset infrastructure management and maintenance is enhanced in a sustainable way. We are pleased to say that fruitful outcomes have been made from the perspectives of circumstance, location, and enhancement of human capacity. The approach adopted is also expected to be expanded to other fields, regions, and nations in a wider scope.

Key Words: *asset management, pavement management system, technology transfer, sustainabl cooperation, customization*

1. INTRODUCTION

The proper maintenance and management of infrastructure systems is a common issue for countries around the world. It is important for infrastructure administrators to manage both the construction of new facilities and the maintenance of existing facilities using limited resources. In order to successfully engage in proper infrastructure asset management, a management system having elemental technologies, such as a deterioration forecasting model and a life cycle-cost evaluation model, is presented in this study. A common procedure of a management system for an infrastructure is the provision of useful results for the decision maker using collected information. However, the requirements for the maintenance and management of infrastructure vary considerably among organizations, countries, and facilities, thus, one closed management system alone cannot satisfy all maintenance and management tasks. A management system that responds flexibly to any situation, such as the institution, history, level of service or style of output, is needed. In addition, it is important for proper infrastructure asset management to implement a PDCA (Plan - Do - Check - Action) cycle continuously and to improve the work style and output step by step, which also requires modifying the management system continuously to make it consistent with the PDCA cycle. For that purpose, the department in charge of management system control needs to understand the system deeply, and consider how to enhance human capacity from the viewpoint of a long-term strategy.

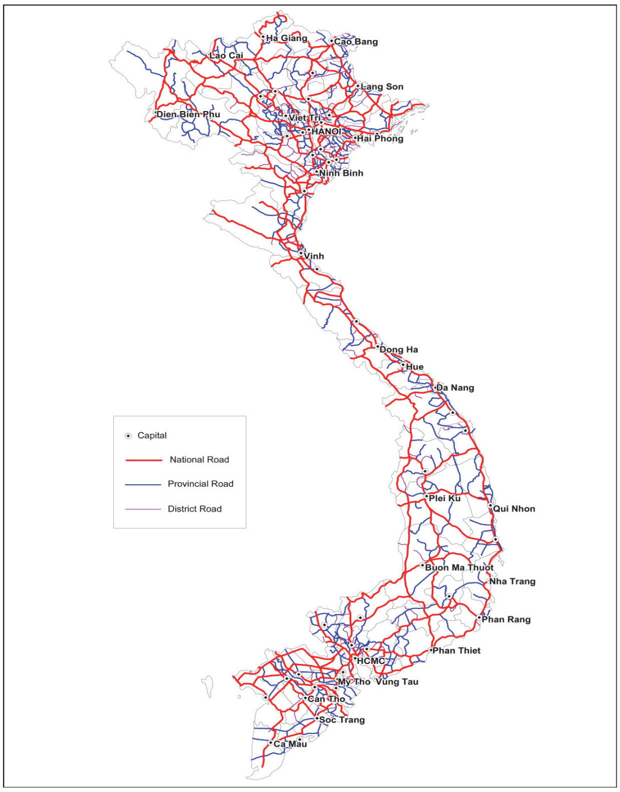
Based on this background, this paper aims to extract important points to be considered about collaboration with relevant organizations and practical activities when a new infrastructure management system is introduced by analyzing a case study of the introduction of a pavement management system (PMS) in Vietnam. In particular, the practical activities in the process of the cooperation program among industry, government, and academia research groups in introducing the infrastructure management system into Vietnam and in a subsequent project are reported, and useful knowledge acquired from their process and activities are analyzed and evaluated.

2. BACKGROUND OF THIS RESEARCH

(1) Road network in Vietnam

With typical land features of being a one-dimensional, stretched-out country from north to south in an S-shape with land borders with Cambodia, China, and Laos, transportation plays a key role in economic and social development, as well as in national security in Vietnam. The country has a diversified transportation system that consists of different major models: roadways, railways, airways, seaways and inland waterways. Road transportation is the most significant model having the highest contribution in terms of transportation sharing with 2,011 million passengers, accounting for nearly 92% of the total; and 585 million tons of goods, accounting for nearly 73% of the whole transport sector, according to statistics from fiscal year 2010[3]. Therefore, the road infrastructure has been developed and expanded continuously, not only in quantity in terms of the number of routes, facilities, and road length, but also in quality to conform with increasing transportation demands, especially since the Doi Moi (economic reforms).

National highways and expressways are the core



Source: Directorate for Roads of Vietnam

Fig. 1 National road network in Vietnam.

road network for the whole nation. Of these, expressways are very new systems that have just been initiated, with around several hundred kilometers in operation. There are 92 routes in the national highway network, with a total length of approximately 18,000 km corresponding to a share of around six percent of the total road network.

Among developing countries, Vietnam is a good example of the utilization of proper strategic policies to promote industrialization, modernization, and national development. Many great achievements have been made in different fields including the transport sector. The fruits of road infrastructure development to date have been achieved, thanks to the right direction and proper governance of the Communist Party and the state, domestic efforts, and great support from donors, international organizations, and many countries, including Japan.

(2) Approaches to PMS introduction

Being aware of the significance of road infrastructure management and maintenance to achieve a successful transfer from generation to generation, much attention has been paid to the matter. The introduction and application of road management systems such as The Highway Development and Management (HDM-4) started in the 2000s. Many efforts for system operation and application had been made, including financial investment from state budgets

Table 1 Comparison of approaches to the PMS system.

Evaluation index \ Option		Use commercial off-the-shelf software	Ask system developers to modify existing off-the-shelf software	Develop a custom system
Application	Cost (Budget + time)	O / x	x / Δ	x
	Initial application (effort to develop)	O	Δ	x
Operation	Matching current condition (data)	X	Δ / O	O
	Satisfying current objective (result)	X	Δ / O	O
Future issue	Extending future demand (function)	X	Δ / O	O
	Copyright	X	x / Δ	O

Note: "O" - Good, "Δ" - Reasonable, "X" - Bad

and ODA funds since the last decade, but the outcome ended up far from expectations due to both subjective and objective causes, especially the low ability to customize "closed" systems due to local conditions or requirements. The lack of training and dissemination to improve knowledge and awareness in the field of asset management during the introduction of these systems is also one of the main factors that lead to failed application in Vietnam.

Consequently, the implementation of road asset management systems in Vietnam was pushed to such a critical situation that everything now has to be restarted from the beginning, a little more than one decade after the launch of the system. Three approaches must be considered: (1) continue to use commercial off-the-shelf software, (2) ask system developers to modify existing commercial off-the-shelf software, or (3) develop a customized system, as shown in **Table 1**.

Past lessons show that now, with many advanced technologies available and high demand for customization, the first approach is not a good choice. Moreover, it is also less practical to select the second approach because off-the-shelf software is "closed" and cannot be modified by users. Hence, the third option seems to be the best choice given the ready availability of many open-source systems such as the Linux Operating System. However, without experience in developing road asset management systems and also with the complications and sophistication of system features, the possibility for success in the third approach may also be very low.

Continued demand for proper road asset management is a matter of course, even in developed countries such as Japan. However, differences can be seen, and initially, the third option had been decided upon in Japan, and this decision has promoted many research studies.

The PMS Kyoto Model was used to study pavement deterioration in Vietnam within the framework of academic collaboration. The results were presented in international seminars that have been highly appreciated by Vietnamese road administrators, and representatives of the road sector expressed the desire to develop a new PMS for Vietnam based upon the PMS Kyoto Model[4)].

In 2011, the Japanese government approved support for a number of Vietnamese government programs, including a cooperative project for capacity enhancement in road maintenance that consists of one component on enhancing road maintenance planning. For this component, the Kyoto Model was selected for customization so as to develop a new PMS system for Vietnam. It has been available since March 2014, and is ready as a capable tool to support making both mid-term and annual plans for pavement maintenance.

In this paper, the following section presents the history of the application of closed PMS systems. The lessons learned from this application is one of the reasons for changing the direction of approach to "open" PMS systems, as discussed in Section 3. Sections 4 and 5 describe the approach and development of a new PMS based on customization of the Kyoto Model within the framework of the support of the Japan International Cooperation Agency (JICA). Finally, recommendations are proposed to ensure sustainability of the system in Vietnam.

3. HISTORY OF PMS SYSTEMS AND LESSONS LEARNED IN VIETNAM

(1) Introduction and application of PMS system

a) Development and deployment of HDM-4

The development of an integrated road investment evaluation model for developing countries by the World Bank became the prototype of HDM back in 1968. The first model was the road cost model (HCM: Highway Cost Model) developed in 1971 by the Massachusetts Institute of Technology (MIT). Afterwards, the Traffic Research Laboratory (TRL) of the United Kingdom executed large-scale field surveys in Kenya in collaboration with the World Bank (WB). The results of the field surveys for empirical study were used to modify the prototype of the road investment model (RTIM). Additionally, this result was used to create an extended version of HCM and RTIM, and became the HDM. In 1994, the microcomputer version HDM-95 (Archonodo-Callao) was built as the result of field surveys and advancing computer technology. Version 2.0 of HDM-4 was released in 2006 through HDM-III, Version 1.0 of HDM-4 in 2000 and Version 1.3 of HDM-4 in 2002[4]. HDM-4 is a software tool that is used to appraise the technical and economic aspects of road investment projects, excluding a database function.

Various versions of the models have been widely used in a number of countries, but success stories in operation have not been reported or released to the public very often. Different models have been used to investigate the economic viability of road projects and to optimize economic benefits for road users under different levels of expenditure.

Since the initial introduction in Vietnam for national roads in 1988, six trials were conducted up to 2006 by the WB and the Asian Development Bank (ADB). The HDM-4 trials carried out from 1998 to 2006 mainly used a common dataset format to formulate datasets for analysis, without relying on an external database. In 2007, the Vietnamese Road Agency (VRA) made a decision to use database software as the official database software in an attempt to convert data into the HDM-4 dataset. This is because HDM-4 can prepare its dataset in two ways: by directly constructing datasets in the HDM-4 format, or by converting and importing data from an external database to formulate datasets for analysis.

b) Development and deployment of the database system

In 2007, the VRA made a decision to use the database system as a database tool for national road maintenance management. The first data collection and input into the database system by the VRA on its own was carried out in 2007. However, after a field survey, many critical issues with this database system were pointed out. Here are some typical points: (1) insufficient functions to support daily maintenance and management, (2) difficulties for the regional staff in handling the database and the system due to the lack of technical support from the supplier, including limited training, (3) difficulty in sharing data input tasks among staff, (4) insufficient functions for data input control, and (5) impractical reporting functions.

The database system was expected to play a role as an external database for data conversion to create a PMS dataset for HDM-4. However, due to the low reliability of registered data and system problems, the database system ceased to be operable[4].

(2) Lessons learned from application of PMS

Mid-term and long-term planning systems for road maintenance in Vietnam are not in operation at present due to the complexity of operation, poor customization features, low database reliability, and system troubles with the database software[5]. As a result of these long trials and applications in the past, valuable lessons have been obtained, which will be described below.

a) PMS should be changed from commercial- and black box-based systems to an open source-based one

PMS must be fully understood as one system with a macro scope of application that reflects many national issues in terms of technical, institutional, policy, budget, etc. Hence, PMS development must be dealt with in a very different manner from common commercial software. Thanks to the recent dramatic improvement of informatics technology, development of a new PMS system specifically for road administration has been confirmed to be the best solution.

Regarding technical issues, the PMS system seems to be very sophisticated, in addition to having the potential for many changes, leading to a very high demand for improvement and customization of the system during utilization in order to support proper management and maintenance of road asset infrastructure. In this case, the copyright in commercial systems or source code in black-box or closed systems has become a very serious issue that can be a critical barrier to any desire for system improvement. In light of this situation, an open source system is the obvious choice.

b) Improvement of involvement and collaboration among stakeholders and public announcement

In terms of improving organizations in various fields, research and development (R&D) always plays a significant role. However, in Vietnam, it must be understood that the R&D function in many organizations and agencies, especially in domestic businesses, is rather poor, which seems to be the main barrier to improvement. Given such a situation, there is a need to enhance collaboration among relevant organizations, especially among state management agencies, businesses, and research organizations such as universities and institutes. Application and utilization of previous PMS systems are quite limited for some organizations, without sufficient collaboration with R&D agencies to sustainably absorb technologies.

Moreover, it also has proved difficult to find key engineers who are well acquainted with the operation of the previous PMS systems. The combination of insufficient dissemination of recipient organizations and poor involvement on the part of competent agencies has led to a more challenging situation in terms of making the systems the officially adopted ones. HDM-4 had been used as a tool to create road maintenance plans for submission for approval of budget plans. However, there are no strong or persuasive arguments to make financial agencies recognize the method of budget simulation used in HDM-4 because, in general, they had very limited information on, or understanding of it.

In order to avoid replicating this problem, the new system should be a simple but powerful tool for creating outputs that are logical, informative, and illustrative. The work effect in each maintenance scenario needs to be clarified to show not only the role and commitment of road administrators in guaranteeing road networks for a given level of service but also the responsibility of financial agencies and the government in securing an adequate budget allocation.

c) Training is indispensable for improving human capacity

Unlike common computer software, specialized systems such as PMS require training in operation, as they are specialized software for road management. With projects for the introduction of these systems, training during project implementation was provided by the donors' consultants. Therefore, after the projects, there was poor expansion of training or dissemination of knowledge because of the lack of local trainers.

d) Formulation of PMS dataset should be improved in both methodology and technology

Right at the beginning of the introduction of HDM-4 in Vietnam, there was much confusion about how to formulate the dataset for HDM-4 operation. To cover the very broad objectives, the structure of the dataset is rather complicated and very large. For each road section or sample, 159 data items[4)] need to be entered manually into the dataset. In addition, the collection methods for these data items vary, and there should be guidance on how to acquire them. The classification method for these items was also quite simple, without any consideration for hierarchical levels of data, which meant all these data items had to be acquired at the same time.

Moreover, without database functions in the system—such as data verification or data input control—it was very difficult to verify the quality or reliability of datasets.

The latest technologies in data collection had not been introduced or applied, so it was quite time- and cost-consuming to formulate the requested datasets.

4. NEW APPROACH TO INTRODUCING PMS IN VIETNAM

(1) Global trends in PMS

With the availability of HDM-4, not only Vietnam but many other countries in the world have tried to apply this system since the early 21st century[7)]. However, after studies and trial applications, problems arouse such as the impracticality of data preparation and management, the impossibility of calibration[7)] and untouchable systems, which were taken into account when it came to making decisions.

In 2009, an international seminar on asset management implementation in Asian countries was held in Malaysia with rich involvement from many road authorities, policy makers, practitioners, researchers from 19 countries and donors' representative to share current practices of asset management systems and discuss relevant issues, as well as to share a common direction and perspective for the future. Among many intense discussion topics, it was strongly emphasized that the schemes and local conditions of asset management differ totally from country to country. Therefore, one-size-fits-all systems are incapable of dealing with demands for customization. Participants from many countries agreed on the future direction of asset management systems by approaching new systems expected to be developed with efforts to make them usable, practical, and effective. One-finds-one's-own-size systems seems to be the best solution. However, for the Asian countries, the systems can be initiated from one common platform.

Among the different countries, high and clear motivation and a clear vision for the development of new PMS systems was found, with some preparations underway in a number of countries including Korea, Thailand, and Vietnam. As in Japan, studies on PMS had been actively executed; for instance, Jido, *et al.* (2004)[8)] developed a pavement management accounting system (PMAS) for the road administrators of local governments to execute rational repairs by analyzing the road pavement asset management information system.

(2) Academic achievements and application in Japan

With remarkable achievements in the development of infrastructure stock, great attention has been paid to asset management and maintenance in Japan. R&D functions are strongly encouraged in many central and local organizations in addition to close collaboration between state management agencies or businesses and universities or research institutes that have conducted many studies on the development of asset

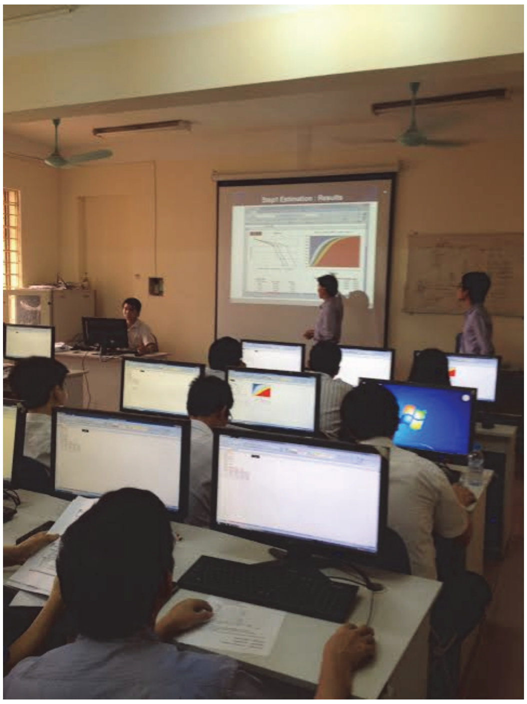


Fig. 2 PMS training course in Vietnam.

management systems.

Breakthroughs in research on infrastructure asset management started in the early 21st century, and the studies are typical of the new approach in the development of more systematic deterioration models—the core component for any asset management system. Stochastic deterioration models using Markov theory have been thoroughly studied for application instead of conventional deterministic models. Through the research, many sophisticated papers have been published since the 2000s to share and disseminate new approaches.

The Kyoto Model is one of the new PMSs to be developed by a research team.

There are differences in road infrastructure management systems between Japan and Vietnam, especially in terms of the involvement of the private sector in road management and maintenance, and the independent demarcation of management schemes among the central government, local governments, and private companies. Therefore, PMS can be different from prefecture to prefecture. During application, the Kyoto Model has been customized to develop specialized PMSs for many prefectures in Japan.

(3) Training program on road asset management in Vietnam

An initiative to enhance capacity in road infrastructure asset management through training was launched in collaboration between Japanese and Vietnamese universities, with ten training courses a year (**Fig. 2**) and four international seminars and symposiums (**Fig. 3**) on the topic being provided for road practitioners, engineers, and researchers in Vietnam within a collaborative framework (**Fig. 4**). Through many discussions, a high demand for development of one new PMS system for Vietnam was found, with the desire for a new approach that should be practical and suitable to local conditions and requirement of customization in Vietnam. With this useful supporting tool, proper decisions can be made with systematic and strategic plans.

Fig. 3 Symposium in Vietnam, 2010.

It has been confirmed that not only engineers and road practitioners, but also many researchers and university lecturers in Vietnam have the chance to know and understand new approaches and knowledge in the field of road asset management including the introduction of, and their understanding of, the Kyoto Model. Much new information has been incorporated into university lectures for dissemination to students.

Research teams also made the effort to conduct case studies on pavement and prediction deterioration models in Vietnam. Results from studies using the Kyoto Model on road pavement were presented at two symposiums, one in May 2010 and one in October of the same year, with significant participation from organizations in Vietnam and the JICA. Representatives of the Vietnam road sector appreciated the studies and highly evaluated the feasibility of the

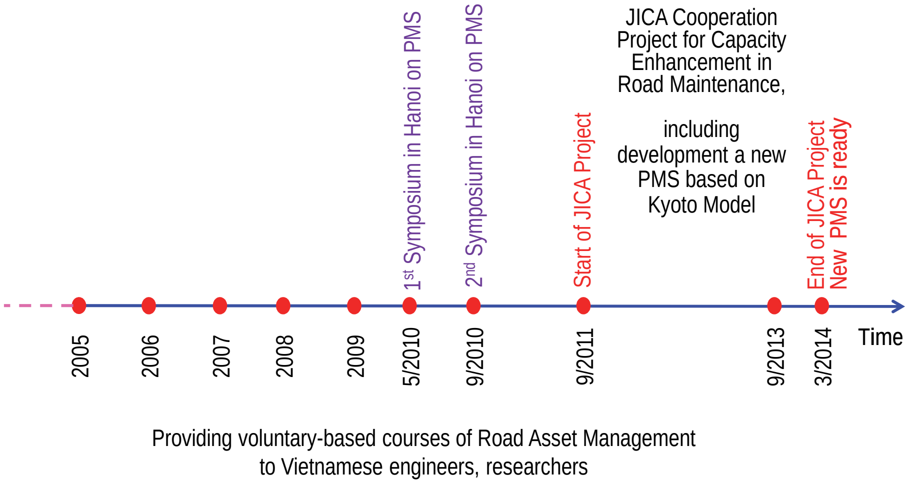


Fig. 4 Main activities to support enhancing capacity in road maintenance and management in Vietnam.

system and the possibility to apply it in Vietnam. Based on that, a proposal to develop a new PMS system for Vietnam based on the Kyoto Model has been officially submitted by the Vietnamese government to JICA for consideration.

For the road sector in Vietnam, their approach to the Kyoto Model is at the extremely critical threshold of changing direction in PMS systems after the long use of HDM-4. However, it is understood that the more important point for the successful implementation of a PMS system in Vietnam are the numerous voluntary-based efforts by Japanese researchers with the aim of enhancing human capacity as the most fundamental preparation for any development.

5. DEVELOPMENT OF NEW PMS BASED ON CUSTOMIZATION OF THE KYOTO MODEL

(1) Practical project for capacity enhancement in road maintenance

A cooperation project for capacity enhancement in road maintenance[9)] was approved by the Japanese government in 2011 based on the request of the Vietnamese government. There are five components offering a comprehensive scope of road management and maintenance, in the project: (1) enhancement of road information management, (2) enhancement of planning capacity for road maintenance, (3) improvement of road maintenance technology, (4) strengthening of road maintenance institution, and (5) reinforcement of human capacity development. There are activities for implementation in each component of the project.

In the second component, the Kyoto Model was selected as the platform for the development of a new PMS system for Vietnam.

During the overall project duration from September 2011 to March 2014, dispatched Japanese experts collaborated closely with their Vietnamese counterparts to study the development of a new PMS system in association with key academic institution.

Among the various ODA projects in Vietnam, in the JICA project, both sides decided to set up a special scheme of cooperation with the goals of realizing the outputs and fully transferring technologies through the project implementation process in order to sustain project outcomes. It had been planned that after the project, Vietnamese engineers should have mastered the systems developed in the project, including operating, upgrading, expanding, and revising the system.

In parallel with system development in the second component, new technology related to the automatic surveying of pavement conditions was introduced, including the provision of a survey vehicle to collect pavement performance data such as roughness, rutting, and cracking. Intensive training to transfer the technology to Vietnam engineers was conducted. The first pavement condition survey was implemented by trained engineers to formulate datasets having high accuracy and reliability in decreasing time for the PMS system.

(2) Core implementation of the formulation of a new PMS in Vietnam

Within the framework of the second component, three activities were conducted: (1) development of a planning system for road pavement maintenance, (2) implementation of a pavement condition survey, and (3) development of data conversion software to prepare datasets for execution of the PMS.

a) Development of a planning system for road pavement maintenance

Based on past lessons learned, both sides agreed to

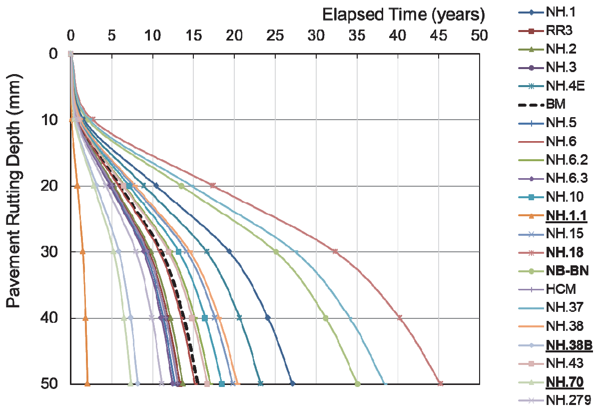


Fig. 5 Benchmarking evaluation in rutting depth for national routes in northern Vietnam.

develop a PMS system specialized for utilization under Vietnam conditions based on customization of the Kyoto Model. This aims to help road operators formulate annual and mid-term pavement maintenance plans on the basis of the pavement condition survey results and statistically analyzed data of future pavement deterioration.

Among the different kinds of maintenance work, proactive or periodical maintenance and rehabilitation are tasks on target for PMS. After-the-fact maintenance of routine works and reconstruction should be dealt with separately from the system.

Mid-term pavement repair plans are developed for terms varying from three to five years after the latest pavement condition survey. The application simulates the progress of pavement deterioration using a Markov hazard model and mid-term budget plans and outputs under three maintenance policy scenarios under budget constraints.

The software system consists of one master database and four modules: (1) Data Management Module, (2) Pavement Deterioration Evaluation Module, (3) Repair Work Planning Module, and (4) Budget Planning Module.

The master database plays a core role in recording database information as well as the conditional information needed for the computation of modules, including those input by operators or those automatically generated through the computation processes.

The data management module imports and updates the PMS dataset into the system, selects data elements from the imported PMS dataset and internally produces data to formulate individual datasets for the other three modules.

The pavement deterioration evaluation module analyzes the pavement deterioration progress and/or the transition of pavement condition states or a pre-defined ranking. The Markov transition probability theory is used in the analysis to calculate the transition probabilities from a given ranking to other rankings of pavement deterioration based on periodically observed pavement conditions to specify the pavement deterioration rate and its life expectancy in each ranking and in total.

To estimate pavement deterioration curves using a stochastic prediction model, at least two time-series datasets of pavement condition must be prepared. However, within the project framework, only one pavement-condition survey was conducted in 2012 to collect the three main pavement indicators of International Roughness Index (IRI), crack ratio and rutting depth. Thanks to the Kyoto Model and its many integrated advanced analysis functions, it is possible to formulate another dataset that just utilizes pavement history data to determine the best condition for pavements at the completion of new construction or the latest major repair. A PMS dataset has been prepared for pavement sections 100 meters long for individual lanes in each direction.

There are various factors that contribute, to a greater or lesser degree, to pavement deterioration. Factor analysis is incorporated in the deterioration evaluation module to identify the most influential factors in pavement deterioration among seven pre-defined factors: (1) heavy traffic volume, (2) pavement thickness, (3) meteorological conditions, (4) pavement type, (5) air temperature, (6) topographic conditions, and (7) repair methods. If road administrators prepare these inventory data, the system can analyze the influence each factor has on the deterioration speed by means of statistical analysis.

In addition, further analysis is made on the variance in the rate of pavement deterioration in the form of relative speed from an average deterioration speed by incorporating benchmarking analysis in the module. The benchmarking analysis can be performed for different groups of pavement sections in terms of road name, management authority, pavement type, repair method, and so forth depending on the availability of relevant data[10),11),12)]. There is no doubt about the great benefits of benchmarking analysis because it can quantitatively point out critical groups of sections with fast or abnormal deterioration that need to be investigated further to specify the causes and proper treatments (**Fig. 5**). For pavements, intensive and structural surveys of loading capacity such as the Falling Weight Deflection test should be performed just for these candidate sections instead of doing tests for all sections. The principle of the classification of data items into different hierarchical levels for utilization and collection has been applied in the system by benchmarking analysis that supports the optimization of data collection in terms of both cost and time (**Fig. 6**).

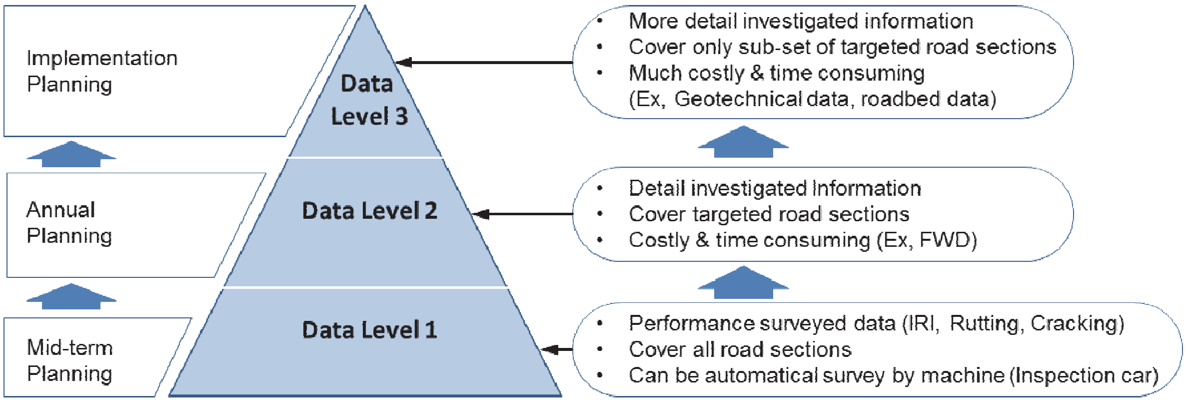


Fig. 6 Classification of pavement data items into hierarchical levels.

Table 2 Flowchart of work repair selection.

Rutting Depth (RD), mm			Light defects				Medium defects				Heavy defects			
			RD < 25 mm				[25 ; 40)				RD ≥ 40			
Traffic Volume (Heavy Vehicle: TV)			TV < 100	[100 ; 250)	[250 ; 1000)	TV ≥ 1000	TV < 100	[100 ; 250)	[250 ; 1000)	TV ≥ 1000	TV < 100	[100 ; 250)	[250 ; 1000)	TV ≥ 1000
Crack rate (CR), %	Light defects	CR < 5 %	No repair				No repair			Cut & OL 50	OL 30	OL 30	OL 50	Cut & OL 50
		[5 ;15)	No repair		Surface treatment		OL 30	OL 30	OL 50	Cut & OL 70	OL 50	OL 50	OL 50	Cut & OL 70
	Medium defects	[15 ; 35)	OL 30	OL 50	OL 50	Cut & OL 70	OL 50	OL 50	OL 70	Cut & OL 70	OL 50	OL 50	OL 70	Cut & OL 70
	Heavy defects	[35 ; 50)	Cut & OL 50	Cut & OL 50	Cut & OL 70		Cut & OL 50	Cut & OL 50	Cut & OL 70		Cut & OL 50	Cut & OL 50	Cut & OL 70	
		CR ≥ 50	(1) Surface & Binder replacement (2) Pavement whole layer replacement (3) Subgrade replacement (4) Strengthening Overlay				(1) Surface & Binder replacement (2) Pavement whole layer replacement (3) Subgrade replacement (4) Strengthening Overlay				(1) Surface & Binder replacement (2) Pavement whole layer replacement (3) Subgrade replacement (4) Strengthening Overlay			

Note: OL means overlay a new asphalt concrete layer on an existing pavement (thickness given in millimeters).
Source: Final Report of JICA Project for Capacity Enhancement in Road Maintenance, 2014

Results of the empirical study in **Fig. 5** shows that of the 21 national routes in northern Vietnam—which cover 47,820 sections in total with performance data collected on IRI, cracking, and rutting—only five routes on the left side of the benchmark case with faster deterioration speeds should be investigated further by pavement load-bearing tests to specify the causes of critical defects and appropriate treatments. The supplemental information can be used to specify maintenance work for repair candidate sections in the flowchart of work repair selection that can be used to make annual maintenance plans (**Table 2**).

Upon completing all the settings required for budget planning, which consist of a repair policy and budget constraints, the module simulates the budget by taking account of all setting conditions using a Monte-Carlo simulation.

The three following maintenance scenarios are taken into account when preparing a proposal on pavement maintenance plans for submission to organizations.

- Scenario 1: keeping the current level of allocated budget (the worst scenario). In this case, the system will help clarify the progress of pavement deterioration when the current budget level is maintained.
- Scenario 2: maintaining the current rate of pavement deterioration. In this case, the system will help clarify the magnitude of the budget that needs to be allocated to retard the progress of pavement deterioration at current pavement-deterioration levels.
- Scenario 3: maintaining pavement condition at service level (the best scenario). To learn the magnitude of repair budgets when maintaining all pavement conditions at target levels (pavement service levels).

b) Implementation of pavement-condition survey

The JICA dispatched a team specialized in pave-

Fig. 7 Implementation of pavement-condition survey.

ment-condition surveying and data processing between February 2012 and March 2013 to collect data on national routes in northern Vietnam with a total length of 2,303 km, corresponding to 4,606 lane-kilometers in both directions. Automatic technology for data collection on pavements was carried out using an automated survey vehicle traveling at highway speeds to increase productivity and improve data quality[15)]. Data were recorded and stored continuously during the survey, which were processed automatically later on in the office, except for the pavement crack ratio, to formulate pavement condition datasets for 100 lane-meter-long sections (**Fig. 7**).

In addition to the three pavement indicators of IRI, rutting, and cracking, other data were also collected during the survey such as road coordinators and road front images at a capture interval of five meters, locations of road facilities, and inventory data. The overall pavement index[13)] can be calculated from the three individual indicators to evaluate pavement soundness and the need for repairs.

c) Development of data conversion software to prepare datasets for PMS running

A dataset is the heart of any management system, especially for PMS with massive data items in terms of both network-wide information consisting of numerous samples and time-series data.

The main idea of development conversion software is to prepare error-free datasets by importing the required data from road databases for running the PMS system. In addition to data importing, conversion software also converts point data on traffic volume into sectional data. Synchronization of location data and homogenous sectioning are also implemented by the conversion software.

Based on past experiences in Vietnam, poor data preparation is one of the main barriers to achieving the above. Therefore, a data validation check is indispensable in the conversion software.

6. SUMMARY AND RECOMMENDATION

(1) Training during project implementation

Previously, in the field of road maintenance and management in Vietnam, there had been many technical assistant (TA) projects from donors. TA projects are very different from cooperation projects (CP), especially in terms of achievement. For a TA project, both the donor and the recipient mostly pay attention only to the outputs that relate to a consultant's assignment and responsibility. Whereas in CP, while outputs are important, transferring knowledge and technology is much more important. This also means that in CP, the recipients' involvement and participation are key points to making them understand not only the outputs but also how to realize these outputs or the full process to achieve the goals.

From lessons learned in previous TA projects for other donors, the JICA decided to formulate CP and make appropriate arrangements for the human resources of projects that were formed through collaboration between JICA's experts and the counterpart's selected members. During project implementation, all relevant issues were raised for discussion to reach common agreement. On the job training was intensively implemented throughout the duration of the project to ensure adequate technology transfer and also to improve the R&D capacity of local organizations including formulation-trained trainers.

(2) Enhancement of human capacity by continuous training program

Collaboration with many non-recipient organizations has been strongly emphasized, especially with respect to introducing the new PMS in Vietnam. It has been strongly confirmed that out-of-the-project frameworks—annual summer courses on road infrastructure asset management conducted since 2005 for Vietnamese engineers, practitioners, and researchers on a voluntary basis—have made a great contribution not only to the enhancement of human capacity, but also to increasing the awareness of decision makers and the public on road asset management and maintenance. During project implementation, we also agreed to change the direction of contents for their training courses by placing more focus on the Kyoto Model—which covers comprehensive issues from fundamental knowledge and theory, model building, practices, and trial running—so as to offer learners good opportunities not only to understand the system but also to get motivation and involvement. Such a scheme is expected to be disseminated and applied in many other places.

(3) Customization to apply local conditions

There were various practices on the implementation of the Kyoto Model in Japan prior to their selection for the development of a new PMS system in Vietnam based on its platform.

In its theoretical approach, the methodology is unique for all applications with the core of a deterioration forecasting model. However, in actual practice, the contents and components of PMS can vary for each system depending on the conditions and constraints of local application.

First, the system should be operable and fully functional, but simple without placing unnecessary burden on road administrators that will make them lose their initial motivation—especially in data preparation, which has been recognized as one of the main causes for failure in the application of previous PMS systems in Vietnam. Available information and data in hardcopy have been used to full advantage to formulate one time-series dataset instead of expending great resources of time, budget, and manpower on a second pavement-condition survey. Also, it was decided not to propose some minor functions, such as an illustrative display on WEB-GIS, to ease data preparation work.

The second point of local requirements for customization was related to the output of the mid-term maintenance plan. There was a common understanding that the mid-term plan focuses on budget simulation to formulate budget proposals of corresponding maintenance scenarios rather than the preparation of a detailed work volume or list of pavement repair sections as in annual planning. However, according to regulations under the State Budget Law in Vietnam, in any budget proposal, there must be a detailed work volume. Determination of the pavement work volume for repair sections in annual planning is made based on surveyed pavement conditions of each single pavement section, maintenance criteria or policy, and the flowchart of repair selection. However, for future roadwork in mid-term or long-term planning, only forecasted pavement conditions are used, rather than surveyed data. The Kyoto Model integrates benchmarking analysis that can predict the deterioration process not only for the whole samples on average, but also for each homogeneous group of pavement sections. **Fig. 5** shows one example of the performance curves for different national routes. In more detail, the pavement performance curve per kilometer has been forecasted to estimate future conditions of 100-meter sections.

One more main point of customization is the setting of criteria used to evaluate pavement conditions and the flowchart of work repair selection (**Table 2**). There is no difference in the approach, but these pre-set values must reflect not only technical issues such as current practices of pavement maintenance and design specifications, but also the national socioeconomic status.

In the reality of the implementation of road management in the future, there will be increasing requirements in the newly developed system that demand continuous customization. It seems that such further demands will mostly focus on: (1) further expanding its functions such as integrated WEB-GIS, data processing, and calculation issues; and (2) customization for application to other road systems such as expressways, urban roads and local roads, and to other road facilities.

Moreover, in the rather remote future, with the increased involvement of the private sector in transport infrastructure investment, management, and operation, the PMS system can be customized, taking into consideration road authorities, owners, and maintenance companies.

There is no doubt that other countries—especially Asian countries—will implement a similar approach by imitating the basic platform of the developed PMS in Vietnam. In such cases, the customization demand will be more specialized.

For the vision of sustainable implementation of the PMS system, two main issues were taken into account during PMS development to satisfy various demands for customization and improvement. An open source-based system is the highest priority that is followed by organizing PMS system in different modules.

7. CONCLUSIONS

Long experience with major lessons learned regarding the application of closed-asset management systems lead to a decision to adopt an open system as the new direction. From the beginning state of the development of a PMS system, a new one based on the platform of the Kyoto Model is now available for operation as the achievement of fruitful cooperation between Japan and Vietnam to enhance road management and maintenance in Vietnam.

The new PMS system is also consistent with the new international standard for asset management ISO55000[1)] that was published in January 2014. The system uses a methodology that estimates a deterioration model by using repair history data, and available datasets of pavement conditions periodically collected through its life cycle. The estimated performance curves explain the tendency for pavement deterioration. Budget planning for different maintenance scenarios will be made based on performance curves and repair policies or a flowchart of repair selection taking into account the priority of candidate repair sections. A benchmarking evaluation is also a useful function to identify target groups of pavement sections having fast deterioration speed to formulate a plan for detailed investigation, as well as to verify the appropriateness of pavement technological alternatives under certain conditions.

It is highly emphasized that based upon technology transfer within the JICA project and continuous support from Japanese researchers and experts, engineers in Vietnam road authorities can easily customize the system by changing preset values such as budget constraint, pavement ranking definition, repair policy and selection, especially upgrading and expanding the system to meet new demands in the future.

It is now time for road authorities in Vietnam to take their turn at disseminating the outputs of the ICA project including the new PMS system to be put into operation. The provision of training by the central authority to regional ones should be considered a key issue in this respect.

Negotiations with competent organizations to make the system official should be made to promote official application for approval of budget plans prepared by the system and new items of budget allocation for periodical PMS dataset preparation. It must be understood that data preparation is not free of charge, and there must be sufficient financial arrangement in conformity with the requirements of data for the PMS system. Informative calculation results from the PMS system—especially the work effect model to clarify the contribution to, or effect of each budget investment scenario on road performance—should be made public to raise people's awareness about the significance of road maintenance and protection in addition to simply having them pay their taxes.

In addition, there should be proper institutional arrangements to assign system management including upgrading and expansion to appropriate units with sufficient R&D capacity. In addition, maintaining collaboration with relevant agencies is indispensable.

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