A SCHEME OF OPEN-SOURCE HYBRID PAVEMENT MANAGEMENT SYSTEM FOR AN INTERNATIONAL STANDARD*

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1. Introduction

This paper introduces a development scheme of the hybrid concept-based pavement management system as open-source software. A reason for being of the PMS (Pavement Management System) of every country may be similar. However their current PMS situations and impeding problems are usually different from each other. Those differences lead to appearance of various PMS models having different frameworks and functions. Although a customized PMS model which is separately developed for a user's situation is preferred, the task may be not so easy because it takes time, money and technical problems, particularly in developing countries. In practice, many developing countries have introduced ready-made software (*e.g.* HDM-4; Highway Development & Management-4) but they have often been falling into difficult situation due to inconsistency between their reality and the model.

The aim of the hybrid PMS is serving a customizable general PMS framework to appease every country, every condition and every objective. That is, the hybrid model serves PMS resources to road agencies to have a customized PMS model by minimized effort. This might be a hard challenge, but many users will benefit by the synergy effect of the hybrid system once it is successfully established. This paper addresses the strategies for realizing the hybrid concept-based pavement management system. As would be expected, there are so many contents have to be discussed in detail. However, this paper presents only general descriptions about the basic concept, required functions, model framework, and customization and operation strategy due to the level of description.

2. Demand of the hybrid model

The PMS model treats past (data accumulation), present (PMS operation) and future (the best strategy) of pavement management by using database, management function, pavement deterioration forecasting model, Life Cycle Cost Analysis (LCCA), and accounting function. However, there is few system including all of components required for pavement management. Most models have limited functions, and also have different definition about each component because the PMS model is developed under a specific situation and purpose. When the system is required to expand functions for better pavement management, the users have to improve their model by investing time and money which is one of social costs. What is worse, the ready-made software users have to wait next version, or give up their desired functions.

Second, every country is in a different situation about kinds of PMS data, law & policy, technical level, equipments and current PMS model. Thus, one PMS model cannot satisfy all users' objectives. For example, very sophisticate pavement deterioration model requiring well-grounded time-series pavement performance data is useless for someone who does not have enough data, even if the model is absolutely wonderful. The best way is, of course, developing customized PMS model for oneself. However, it is never easy because it needs enormous efforts. Moreover, many countries, particularly in developing countries, do not have deep interest or do not recognize an importance of road asset management because their interests or priority of their budget are usually toward construction than maintenance. Much series problem is most road administrators think it much troubles to change their current system because changing current PMS structure is much difficult than developing new system.

Third, there are many cases adopting ready-made software or already developed customized model from someone. In this case, usually compatibility becomes a problem. However, the road agency cannot modify the model due to copyright problem, technical limitation, or the program is a black box.

The hybrid concept-based PMS model can mitigate those problems by rich contents, flexible structure, customization strategy,

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and operation strategy. Details of the methods will be addressed in following chapters.

3. Properties of the hybrid PMS model

Since the PMS structure is very difficult to change once it is established, the decision for the PMS model should be determined at the beginning stage of the PMS development or implementation plan. About this issues, Uddin[1)] classified PMS software implementation strategies into three. 1) Application of ready-made PMS model, 2) Modification of ready-made PMS model, and 3) Development of customized PMS model. The strengths and weaknesses of the alternatives are compared in **table 1**.

Table 1. Comparison of strengths and weaknesses of PMS model implementation

	Ready-made software	Modifying ready-made software	Customized software
Strength	· Cheap · Easy to apply · Good at outset of PMS implementation	· Cheap · Minimizing effort to develop (near) customized PMS software	· Best adaptation for present and future · Easy improvement without copyright problem
Weakness	· Could be expensive · Technical dependence · Inflexibility · Compatibility	· Could be expensive · Difficult to customize · Very rare case due to copyright · Unstable situation	· Most expensive · Technical problems · System maintenance
Evaluation	· Suitable for small to medium size government or developing country · Technical and funding problems · Good at initial stage of PMS	· Suitable for developing or developed country · Problems on being under unstable situation · Second-best alternative but unstable	· Good for every country · Useful for unusual situation, and special objectives · Should be the preferred alternatives

At first, maybe some readers think that starting with the customized software would be the best strategy. But a much better way is gathering only strengths from the alternatives. This way naturally leads to the hybrid concept. The strategy gathering strengths and also removing weaknesses from the alternatives can be realized by following properties. 1) Free software, 2) Open-source software, 3) Rich PMS functions, 4) Flexible system architecture 5) Itemized (encapsulated) functions. The properties are not separated one. By harmonizing the properties, the hybrid concept can be established. Based on these properties, the hybrid model can be defined as: *"A total system under customizable structure including integrated database system, management functions and various deterioration models with LCCA and accounting functions to satisfy all users' various objectives and PMS condition"*.

The strategy of the hybrid PMS model is partially similar with the first alternative by the viewpoint of supporting ready-made software to users. A usual problem of the first alternative is the software already has developer-specified model framework and functions which cannot be modified. It may disturb successful settlement of the ready-made software to users. However, the hybrid PMS model has various (enough) functions by referring general demands of pavement management field to appease every user. In addition, the functions can be easily customized by just detaching useless functions, modifying unmatched parts of function, and adding user-developed function by their demands. This is possible because the hybrid PMS model is following the open-source format, and supporting rich functions. This feature may cover the weaknesses of the first alternative.

The second alternative also has similar point with the hybrid PMS model so that the user can modify the existing model. By the second alternative, efforts to develop customized PMS software could be reduced. This alternative might be considered as a second-best way. Even if the model allows modification, it is very difficult to customize because the user must understand developer-specified all resources in the model. Basically, the case allowing modifying original resources is very rare (or business model). Worst of all, the road agency is being under technical dependence and unstable condition. As an example, the Vietnam road administration has been applying an order-customized PMS software of the RoSy system by investing enormous budget. It was designed for every branch office in the country. However, only several engineers can apply the system from all over the country due to complex system environment. It is, of course, impossible to modify by themselves. Undoubtedly, this is a failure case of the second alternative. About these problems, the hybrid PMS model suggests the hierarchical system architecture with encapsulation strategy. By the strategies, all functions in the hybrid model becomes easily attached and detached from the main body. Since the hybrid PMS model is based on modulated components by functional level like *'Plug-in system'*, the system environment can help development of customized version. Above all, users do not have to understand all resources. It is enough to understand only a capsulated function.

The last alternative, developing customized software, should be preferred alternative. However, road agency should sacrifice many things to carry out (and keep) the alternative for new development and continuous feedback. The hybrid PMS model mitigates this problem by a distribution and operation strategy. Since the all users have same (or similar) PMS framework, useful functions customized (or newly developed) by other users can be shared by joint ownership. This is the best benefit of the hybrid PMS model. This is available by combination of properties of the open-source, the flexible framework, and the encapsulation strategy. The flexibility is one of most important characteristic of the hybrid concept based approach. Plus, maintaining the joint ownership of software among the users would be a main factor determining a life span of the hybrid PMS model.

4. Definition of PMS functions in the hybrid model

In general, designing PMS model targets demands of road agencies. However, the hybrid PMS model aims at unknown users who are related to the PMS (*e.g.* students, researchers, field workers and road administrators). Hence, the hybrid PMS model must have rich contents to satisfy them at the same time. The general functions in the hybrid PMS model are classified by the hierarchical concept by consideration of data requirement and level of demands (importance). Determined and classified functions are summarized in **table 2**.

Table 2: General functions in the hybrid PMS model

Functions	Core level	Semi-core level	Recommended level	Advanced level	Unique level *
Accounting	Short term accounting**	Mid-long term accounting by economic indices	Optimization-I (By network-based approach)	Optimization-II (By section-based approach)	Additional budget contents to optimization process
Economic Analysis	Agency cost	Adding simplified user cost	Adding full user cost	Adding social and environmental cost	Additional LCC (*e.g.* workzone effect)
Deterioration Forecasting	Deterministic - I (Simplified regression)	Deterministic - II (Multiple regression)	Stochastic - I (Markov hazard model)	Stochastic – II (Local mixture hazard model)	Stochastic - III (*e.g.* MCMC, Hidden Markov model)
Management	Work demand, Data error process	Work design, Work effect	Budget estimation	Optimization (Short term-year)	Web-based system
Database	Basic searching, updating data	Data export, Report export	Support for external models (HDM-4)	Visualization (with GIS)	Including the other road facilities

Note: Not the basic functions but examples of extendable function by user's demands*

*** Same with the function in the management level*

In table 2, the PMS functions were classified by the database, management, pavement deterioration forecasting, economic analysis and accounting function. Once more, the functions were subdivided by level of demand. Users can choice reasonable functions to build their customized PMS model by consideration of their data condition and objectives. However, users have to consider that several functions have subordinate relationship between functions. For example, economic analysis is not available without pavement deterioration forecasting function.

Since the database should keep all historical data and support data requirement of the internal and external models, the contents in the database should be rich. The definition of database about contents and tables could be differed by user's customization schemes related to user's desired functions.

The management function does important roles for the PMS operation for estimating work demand, work design, work effect, budget estimation, and optimization. This should be a set with database. That is, the database and management functions are minimum requirements for PMS operation.

For the economic analysis, the pavement deterioration forecasting function is a core element. Since the pavement deterioration forecasting is totally depended upon the historical performance data, it is expected that there are many limitations to application of the forecasting models. In general, there are many noises in the pavement performance history data, thus usually stochastic models are preferred than deterministic models. However, the simplified deterministic model which requires simplest data is also required for users who do not have enough data. For that reason, the hybrid PMS model should have various deterioration models by consideration of data requirement and purposes of forecasting models. The user who is in a beginning stage of PMS development may be use the simplest model due to data requirement. However, as time goes by, their data would be accumulated, then finally they can use the much better (also much more) models in future. The strategy having various deterioration models was for consideration of data requirement, but the strategy also has a benefit for preparation of future demands.

To enhance cost-effectiveness of budget, the economic analysis is essential. The economic analysis is following a concept of the Life Cycle Cost Analysis. The definition of the LCC contents also can be customized by data condition and objectives of users. Lastly, the accounting is used for maximizing cost-effectiveness of constraint budget. Since this function is available without consideration of data condition, all users can use the general accounting functions. The optimization ways will be based upon a comparison of the cost-effectiveness of projects (or maintenance alternatives) by using the results of life cycle cost estimation.

5. System architecture

This is an important and difficult task that concludes successful development and application. Determination of unit (capsule) of functions, and designing exact relationship among the many components are main points. As would be expected, the hybrid PMS model has very huge architecture including sophisticate procedures to serve rich functions and easy customization environment. But this architecture can be easily disaggregated and aggregated by adopting the *'Plug-in system'*. Based upon the database, each function has systematic and subordinate relationship in the hybrid model. This is also one of strategies for easy customization. **Figure 1** shows the concept of the Plug-in system of the hybrid PMS model.

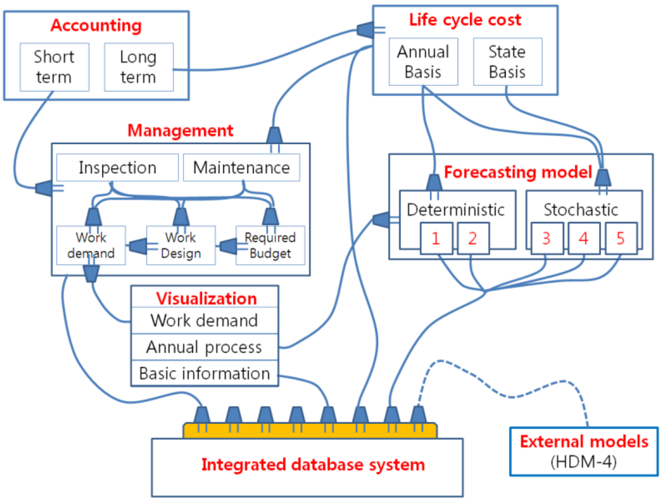

Figure 1: The *'Plug-in system'* of the hybrid PMS model for flexible system architecture

6. Customization strategy

This chapter should be highlighted for successful application of the hybrid PMS model. Easy customization and user-friendly system environment are critical points determining success of the hybrid PMS model. Regarding the strategy, there is several the keywords to be explained; 1) Customization philosophy 2) Hierarchical customization scheme, 3) Plug-in system 4) Encapsulation and 5) Compatibility (with user's current system).

The first keyword, the customization philosophy, is about 'Who do the customization?' The basic philosophy of the hybrid PMS model will follow the concept, *'One finds own size'*. This concept is could be metaphorically expressed by clothing. For example, '*One size fits all'* means every person wears same cloth designed as *'free-sized'* this case could be compared to the HDM-4. In case of *'One finds own size'*, each person makes garments (even bags, curtains) by using fabric based on their demands and skills. In brief, the hybrid PMS model provides pre-designed fabrics with detail instruction to users.

The second keyword, the hierarchical customization scheme, well explains overall concept of customization strategy. To explain the strategy, there are four basic concepts to be understood; *1) Many-to-one, 2) One-to-many, 3) One-to-One 4) Many-to-many*. The *'Many-to-one'* is same with the *'One size fits all'* concept. This means the hybrid PMS model serves enough PMS components to appease everybody. This concept determines the overall shape of un-customized hybrid PMS system. The second, *'One-to-many'* equals to *'Many sizes are prepared for one'*. This concept explains distribution ways by definition of standardized versions following the functional relationship, (*e.g.* by Demo / Standard / Full / Advanced / Unique version). The *'One-to-one'* concept could be compared to the *'Tailor made size'*. This concept means each user can change everything of developer-defined functions and structure to have suitable PMS model for users. The last one, *'Many-to-many'*, is same with the concept *'One finds own size'*. As explained above, the concept determines the subject of customization. If developer or outsourcing company does the customization instead of users, the concept becomes *'One find other's size'*. However, this case has a problem that user must rely on the customizer once user requests the customization to another. In conclusion, the customization strategy of the hybrid PMS model adopts a mixed strategy of the four concepts.

The flexible system architecture can be realized by the *'Plug-in system'* already explained in the **chapter 5**. However, the Plug-in system is impossible without the encapsulation strategy. The term, encapsulation, can be defined as, *making boundary of functions so that changing the original function (source code) does not make effect to the other functions*. In brief, this is a unit of customization. Thus, definition of the boundary is the most important factor for successful customization strategy. The size of capsule has tradeoff relation among system flexibility, simplicity of customization, and convenient application (see **figure 2**).

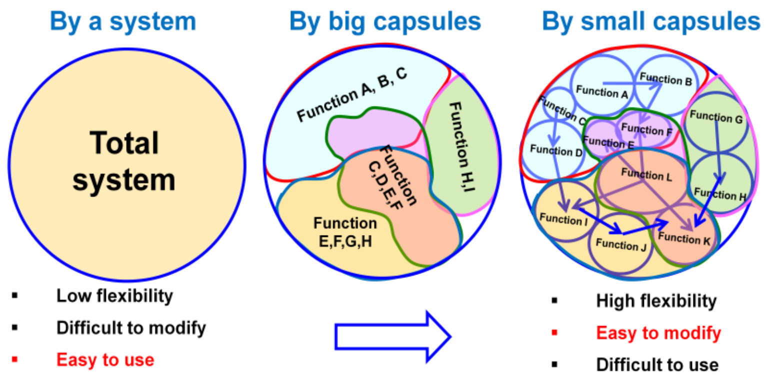

Figure 2: Tradeoff relationship between capsulation strategies.

The hybrid PMS model has many functions, and even each function has sub-models and sub-routines. If the format of the hybrid PMS model takes as an integrated type, it may be much easy to use. However, the system loses flexibility, and also becomes difficult to be modified by users. For example, even if a user wants to modify a small part, the user must understand all source codes, and should check all links affecting to the other functions. Maybe it could be much difficult than developing new program. On the other hand, the subdivided format divided by smaller capsules can minimize effort for customization by modifying routine within a capsule. This alternative could be the best way to realize the philosophy of the hybrid PMS model. However, it also has weakness that many steps are required to reach the final result. Nevertheless, the subdivided format by small capsules has benefits so that user can get intermediate results of simulation, and users can check problems of their customized version one by one.

The last keyword, the compatibility with the user's current system is also a very important issue. Someone may ask "Who will be the users?" This is a very critical question. Usually, most road agencies have a tendency to keep their current system because they think introducing new system may cause too much trouble. In actuality, there are many direct or indirect external-factors linking with pavement management, such as budget level, raising a funding from donors (*e.g.* World Bank, Asian Development Bank), related law and regulations, structure of organizations, technical limitations and so on. For those reasons, nobody can easily discard their current system. This would be the biggest obstacle for improvement of their current system. That is why the sustainable PMS model should be established at the outset of the PMS implementation.

About the matters, the hybrid PMS model contrives two solutions. First, the hybrid PMS model will support user's current PMS by extracting data file from the database so that users can directly apply their current PMS software in use. In brief, user can put their current PMS on the database in the hybrid PMS model. As a default, the database in the hybrid model supports the HDM-4 system which is the most widely applied to pavement management field (used in over 100 countries[2]). This could be customized for user's PMS. The second is supporting useful functions to user's current system by extracting capsulated functions from the hybrid PMS model, such as vehicle speed estimation model, a pavement deterioration forecasting model, and a component of life cycle cost analysis. That is, users can put the components of the hybrid PMS model into their current PMS without system building.

Since the every function in the hybrid PMS model are designed as independence modulus (namely, a separated model), each function can cover the deficiencies of user's PMS. This can be done due to the encapsulation strategy. At first stage, the hybrid PMS model may have to go with users' current PMS. In the beginning stage of application, users may compare the hybrid model with their model, or applies partial functions for their PMS. If the users are satisfied with the hybrid PMS model, they can phase the system in.

6. Operation strategy of the hybrid PMS model

The hybrid PMS model can make a great benefit by the joint ownership among users. After distribution of the first general version, maybe many customized versions would be appeared based upon each user's condition. They can share their customization information, know-how, even capsulated functions . If there are very useful functions which are newly developed or modified by users, the general version of the hybrid model also can be improved by the functions. Afterward, the upgraded version will be served to new users.

As time goes by, their customized PMS model would be similar, or several standardized versions representing specific conditions would be appeared by continues feedback among users. Every user has a different customized PMS model, but they share their model under joint ownership. This is a final goal of the hybrid model to being an international standard of PMS model.

For external pilot-test, many users from the 19 countries (Korea, Japan, Vietnam, Singapore, Thailand, Malaysia, India, etc.) are registered as expected users of the hybrid PMS model. The distribution of countries is good for making examples of various customized PMS model because the countries has different characteristics in terms of economic level, climate, and technical level. By the result of trial-period, the hybrid model could be expanded to the world.

7. Conclusion

Until now, many kinds of software or models relevant to PMS have been developed. However, it is difficult to answer 'Which is the best system?' because the meaning of the best system is not the well-grounded powerful program but the system which is well-describing user's objectives and situation. The HDM-4 model developed by the World Bank could be a good example of this case. For this reason, this paper tried to introduce a scheme of the hybrid concept-based pavement management system to serve the best framework to minimize efforts to develop customized PMS model.

The hybrid concept was contrived from alternatives of PMS software implementation to solve their weaknesses, and to gather strengths only. The properties of the hybrid PMS model were defined as; 1) Free software, 2) Open-source software, 3) Rich PMS functions, 4) Flexible system architecture 5) Itemization of functions. By harmonizing the properties, the hybrid concept was naturally established. These concepts are applied for determining the overall shape of un-customized hybrid PMS model.

The most important term for realizing hybrid concept was the 'customization'. For easy customization and user-friendly system environment this paper suggested the keywords; 1) Customization philosophy 2) Hierarchical customization scheme, 3) Plug-in system 4) Encapsulation and 5) Compatibility with user's current system. These concepts can facilitate easy introduction of the hybrid PMS model.

At the last stage, this paper highlights the benefits of the hybrid model by formation of the joint ownership. By the joint ownership under same framework, they can help each other. Finally, they will have same or similar PMS model by continues feedback among the users. This is the best figure of the hybrid PMS model as an international standard of the PMS model.

Of course, there are several obstacles disturbing vivid application. First is inconvenience for application caused by the encapsulation strategy that requires many procedures to reach final stage. Second, user should have deep understanding about every function and model framework of the hybrid PMS model, even a basic knowledge of the programming language. Lastly, making joint ownership will be a hard challenge.

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