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論文の内容の要旨

Road asset plays a vital role in the economic and social development of a country. Investment and preservation of road asset consume huge resources while maintenance as well as new construction of pavement represents approximately one-half of the total road expenditure. Furthermore, after the initial development of a road network, expenditures for right-of-way and other initial costs cease but expenditures on pavements continue to grow as maintenance and rehabilitation are required. The World Bank (1988) carried out a survey for eighty-five developing countries and estimated that around $45 billion worth of road infrastructure had been lost due to inadequate maintenance over past two decades. This loss could have been averted with preventive maintenance costing less than $12 billion. The role of road maintenance is highlighted when both road agency and road user costs are considered. Technical publications often cite the statistic that for every additional one dollar a road agency spends on road maintenance, road users save two to three dollars. Nowadays, road asset networks throughout the world are extensively deteriorated due to increasing demands while allocated resources to develop and preserve them are reduced in developed countries and constrained in developing countries. Therefore, innovative practices are necessarily required to manage huge investments on pavement systems in an effective manner in order not only to provide a safe and comfortable traveling, but also to maximize benefits to society.

Life-cycle cost analysis (LCCA) has been widely recognized as an economically sound approach for supporting decision-making on pavement designs and maintenance strategies. An effective pavement design process based on LCCA considers not only initial construction but also long-term maintenance strategies, road user effects, and socio-economic context where it is applied. Option evaluation systems (OESs) have been extensively used as useful means for pavement life-cycle cost analysis in both developed and developing countries over the last decades. Examples of OESs include the HDM-III, RTIM, HERS, HDM-4, RealCost, and dTIMS-CT. The major weakness of OESs has been discussed in the literature that they predict the "optimal" option among alternatives exogenously specified. Since there are an infinite number of options, it is impossible to exhaust all of them in order to find the true optimizer. Usually, alternatives to be tested are generated with "engineering judgment", and the situation may not be as bad as "trial and error". However, it does not diminish the necessity of developing a systematic and efficient search procedure that obtains the true optimizer.

Another challenge that we are facing is how to manage road networks which have been substantially completed in many countries. Road organizations, nowadays, have shifted their consideration from project to network level decision making, and from prioritization to optimization approaches for managing their networks in a cost-effective manner. The project level that attempts to evaluate project priorities but does not formally address network-level planning issues as the impact of limited budgets and desired performance goals for the entire road asset. The network perspective allows the user to properly address the trade-off between constituent components of the entire road asset and their associated investments. The entire road asset consists of different components such as pavements, bridges, tunnels, culverts, other structures, road signs and signals. Each component may be further subdivided by road class, administrative region, climatic zone, etc. which may be managed by different road agencies or different divisions of a road agency. Although techniques exist for optimizing the management of individual asset components such as Pavement Management System (PMS) and Bridge Management System (BMS), there is a dearth of techniques for optimizing the management of the entire road asset.

Also, techniques have not been well developed for managing a large asset component such as a nationwide pavement network. When dealing with a large network, it is typically subdivided into several sub-networks according to certain characteristics such as traffic volume and pavement surface conditions. Each sub-network may then be analyzed by using certain systematic methods for optimal management strategies under several budget scenarios, but only ad-hoc manners are used when integrating the results. The reason for subdividing a network may be purely technical in that, explicitly or implicitly, there always exist certain limitations in the number of road sections that can be analyzed by most optimization tools. A large network may also be subdivided for practical reasons such as budgeting purposes and administrative needs. Against this background, it is desirable to develop a unified optimization framework for conducting sound trade-off analyses of all constituent road asset subsystems. The term of subsystem is a generic sense that includes both infrastructure components and sub-networks.

Given the challenges above, our overall objective of this dissertation is to tackle the lack of innovative techniques to support decision-making on optimal strategies of investment and preservation for road infrastructure. In the first chapter, we described problems on the investment and management of road infrastructure systems, followed by a comprehensive literature review and identify the shortcomings from the previous studies for our further improvement. Chapter 2 developed a methodology to combine Gradient Search with Option Evaluation Systems (GSOE) for finding optimal investment options without relying on user specified options. The operability, applicability and feasibility of GSOE has been demonstrated and evaluated for the case study where only overlays were considered as applicable treatments for finding optimal maintenance strategies. To take account of the pavement LCCA using OESs, we have generalized the GSOE procedure to make it capable of finding optimal strategies consisting of both initial pavement design and subsequence maintenance strategies. The unit costs of pavement design and maintenance works are used as the indicator of "works" intensity in the generalized GSOE. Major challenge for solving the optimization problem in such a case lies in the identification of unique relationships between unit costs and engineering specifications of pavement "works". We have developed an efficient pavement design (EPD) methodology to establish a family of EPDs, which have a unique relationship between unit costs and engineering specifications and can be used in the GSOE optimization. Chapter 3 continues with the expansion of the GSOE application for optimizing maintenance strategies consisting of various treatments (e.g., resealing, overlay and reconstruction) so that it may be used for a wide range of existing pavement/traffic situations. Gradient search methods, however, are known to be handicapped by their likelihood to be trapped in local optima and it is not always possible to prove that the objective function used in GSOE is unimodal with respect to the variables defining investment and/or maintenance strategies. Therefore, the use of a good starting point in GSOE which is generated from analytic models may avoid the tendency of being trapped in local optima. Given the availability of TOCM–based methodology proposed by Rashid and Tsunokawa (forthcoming) for optimizing pavement maintenance strategies consisting of various treatments, we used the solution generated by the TOCM as a good starting point in the GSOE procedure in order to obtain the global optima. This combined procedure is named Combined Optimization-Simulation Methodology (COSM) which can be used for searching optimal maintenance strategies consisting of various maintenance treatments without worrying to be trapped in local optima. Along with this chapter, we proposed a systematic procedure to apply COSM for investigating the optimal pavement preservation strategy (OPPS) of a road network (see Appendix D). The OPPS is defined as a set of optimal pavement maintenance options corresponding to various representative sections of a road network. In Chapter 4, we dealt with the network level and developed a Unified Optimization Framework (UOF) for sound trade-off analyses of constituent road asset subsystems, whether be it infrastructure components or asset sub-networks. The UOF employs the net present value as the common denominator for measuring desirability of management program for all asset subsystems. The applicability and accuracy of the developed methodology is evaluated through a demonstration using road sub-networks with OESs.

Finally, given that the methodologies/approaches above have been developed, Chapter 5 presents a comprehensive procedure as a practical guideline for road agencies to conduct the strategy analysis with dynamic sectioning (SDS) of a nationwide road network for preparing the expenditures of the entire road network under various budget policies and economic scenarios. The UOF approach is modified to proceed the sound trade-off analysis of all road sub-networks when considering uniform distribution of annual budgets over the planning period. We also presented how optimal maintenance strategies obtained at the project level by using the developed approaches (i.e., GSOE or COSM) can be utilized at the strategic level for conducting the network maintenance strategy. In a part of this chapter, we present a procedure using the SDS to identify appropriate single or rolling multiyear work programs and prepare contract packages for individual sections of a road network or sub-networks (see Appendix E).

To sum up, the contributions from this dissertation are four-fold. First of all, we have developed a systematic procedure to combine gradient search methods with option evaluation systems (GSOE) that is capable of finding optimal pavement designs and maintenance strategies. Secondly, we have generalized the combined optimization-simulation methodology (COSM) for optimizing pavement maintenance strategies consisting of various treatments so that it can be used for a wide variety of traffic/pavement situations. These two approaches may contribute to the-state-of-the-practice pavement LCCA where OESs are utilized. Thirdly, we have presented the unified optimization framework (UOF) to conduct sound trade-off analyses of all constituent road asset subsystems, whether be it infrastructure components or asset sub-networks. Finally, we have created a comprehensive procedure as a practical guideline for road agencies when they conduct optimization analysis of a nationwide road network under given constrained budget scenarios. Although HDM-4 was used as an OES for developing the GSOE and COSM methodologies, it is desirable to apply these approaches with different OESs to evaluate their adaptability in a variety of applications and to making them more powerful tools for analyzing different management issues. If available, these proposed approaches can be coded in a computer program along with OESs that would reduce computational effort for the analyst when conducting the optimization analysis. For developing the UOF we use the NPV as the common denominator for measuring the desirability of management systems, therefore the methodology can be also applicable for different types of management systems (whether or not be physical condition or operational standpoints) if NPV is available for all these systems. However, we considered only one budget item (i.e., capital expenditures) for the entire analysis period in developing the UOF methodology that points out the future study to enhance the UOF with multiple budget items and/or multiple budget periods in general.

論文の審査結果の要旨

[Background]

Road asset networks play a vital role in the economic and social development of a country but investment and preservation of them consume huge resources. Furthermore, road asset networks throughout the world are extensively deteriorated due to increasing demands while allocated resources to develop and preserve them are reduced in developed countries and constrained in developing countries. Innovative practices are necessarily required to manage huge investments on road asset in an effective manner in order not only to provide a safe and comfortable traveling, but also to maximize benefits to society. Option evaluation systems (OESs) have been extensively used as an useful mean to support decision-making at both project and network levels to manage investments on road asset at the most cost-effective way in both developed and developing countries over the last four decades. Examples of OESs include the HDM-III, RTIM, HERS, HDM-4, RealCost, and dTIMS-CT.

[Objectives]

The overall objective of the dissertation is to enhance the use of OESs on finding optimal strategies of investment and preservation for road infrastructure in an effective manner.

[Major results]

The contributions from this research are four-fold. Firstly, a systematic procedure has been developed that combines gradient search methods with option evaluation systems (GSOE) that is capable of finding optimal pavement designs and/or maintenance strategies. Secondly, the combined optimization-simulation methodology (COSM) has been generalized for optimizing pavement maintenance strategies consisting of various treatments (e.g., resealing, overlay and reconstruction) so that it may be used for a wide variety of traffic/pavement situations. These two approaches overcome the major weakness of OESs that they predict the “optimal” option among alternatives exogenously specified. Since there are an infinite number of possible options, it is impossible for OESs to exhaust all of them and only the best strategy are found among those specified. Therefore, the GSOE and COSM approaches may contribute to the-state-of-the-practice pavement life-cycle cost analysis at project level where OESs Although this research used HDM-4 as an OES for developing GSOE and COSM, the methodology is general enough to allow most OESs to be used in these procedures.

Thirdly, a unified optimization framework (UOF) has been developed for conducting sound trade-off analyses of all constituent road asset subsystems, whether they are infrastructure components or asset sub-networks. The UOF approach contributes to the development of techniques for optimizing the management of the entire road asset in a unified and coherent framework. The net present value (NPV) is suggested to be used as the common denominator for measuring the desirability of management systems, therefore the methodology can be also applicable for different types of management systems (whether or not they be physical condition or operational standpoints) if NPV is available for all these systems. As a prototype, a case study was developed that considers only one budget item (i.e., capital expenditures) for the entire analysis period. Finally, based on the results of the development of these methodologies/approaches, a comprehensive procedure has been developed that may be used in the optimization analysis of a nationwide road network under given constrained budget scenarios. This provides a practical guideline for road agencies in using OESs in their effective road network management.

博士論文は、上記のように博士研究としてふさわしい内容をまとめたものであるものと認められる。