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Research Article

A Compromise Programming Model for Highway Maintenance Resources Allocation Problem

Hui Xiong,[1] Qixin Shi,[2] Xianding Tao,[3] and Wuhong Wang[1]

[1] *Department of Transportation Engineering, Beijing Institute of Technology, Beijing 100081, China*
[2] *Department of Civil Engineering, Tsinghua University, Beijing 100084, China*
[3] *ITS Division, District Department of Transportation, Washington, DC 20003, USA*

Correspondence should be addressed to Hui Xiong, xionghui@bit.edu.cn

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This paper formulates a bilevel compromise programming model for allocating resources between pavement and bridge deck maintenances. The first level of the model aims to solve the resource allocation problems for pavement management and bridge deck maintenance, without considering resource sharing between them. At the second level, the model uses the results from the first step as an input and generates the final solution to the resource-sharing problem. To solve the model, the paper applies genetic algorithms to search for the optimal solution. We use a combination of two digits to represent different maintenance types. Results of numerical examples show that the conditions of both pavements and bridge decks are improved significantly by applying compromise programming, rather than conventional methods. Resources are also utilized more efficiently when the proposed method is applied.

1. Introduction

By the end of the 1960s, major construction of highway networks ended in developed countries such as the US and Canada. The main tasks of highway agencies shifted from planning, design, and construction to management and maintenance of the highway infrastructure, which usually consumes large resources. In the US, for instance, the total investment in highway infrastructure has reached \$1 trillion [1]. In recent years, highway agencies have to face tough budgeting problems in maintaining existing highway facilities. Due to ever-increasing transportation demand, more funds are needed to rehabilitate the deteriorating highway facilities, and the gap between required funds and budgets is increasing. It becomes critical that the limited resources should be more effectively allocated and used.

Consequently, highway asset management, as an effective means for infrastructure management, has received increasing attention. The principle of highway asset management can be defined as a strategic approach to the optimal allocation of resources for management, operation, and preservation of highway infrastructure. Highway asset management emphasizes resource sharing and optimal allocation among all sections of the whole highway network, beyond the scope of single facility management (e.g., pavement management or bridge management). Through highway asset management, the limited resources can be used more effectively. Hence, the infrastructure will better serve the needs of road users during its life cycle. The conceptual core of highway asset management is resource allocation [2].

Highway asset maintenance management (HAMM) is a critical element of highway asset management. Through its integrated management for all components of the entire highway system during its life cycle, the objective of HAMM is to optimize resource allocation in a wider range and find the highway maintenance solution that minimizes the costs or maximizes the benefits, considering the resources constraints in funds, labor, and equipment. Specifically, HAMM will solve such questions as when and how the maintenance should be implemented. Since different maintenance types and implementation times would yield different performances, the HAMM process finds the optimal combinations in order to achieve stated objectives. The resource allocation problem in HAMM is usually a multiobjective problem. The main task in solving multiobjective problem is to obtain Pareto-optimal solutions. As an effective method for solving a multiobjective problem, compromise programming (CP) was developed by Yu [3] and Zeleny [4]. In recent several decades, CP was broadly applied in many fields.

Lounis and Cohn [5] applied compromise programming approach to select satisfying solution for multicriteria optimization of engineering structures and structural systems. To solve multicriteria decision making in irrigation planning, Zarghaami [6] formulated compromise programming models with multiobjectives such as regulation of reliable water at the demand time, improving rice and tea production, domestic water supply, environmental needs, as well as reducing social conflicts. Diaz-Balteiro et al. [7] applied compromise programming to rank sustainability of European paper industry countries in terms of 14 indicators including economic, environmental, and social indices. It was found that the results were robust when different preferential weights were attached. And the methodology can be applied at a more disaggregated level and other indicators can be introduced. Amiri et al. [8] proposed a Nadir compromising programming (NCP) model by expanding a CP-based method for optimization of multiobjective problems in financial portfolios. The NCP model was formulated on the basis of the nadir values of each objective. Numerical example of a multiobjective problem to select optimal portfolio in Iran stock market proved that the NCP model can satisfy decision maker’s purposes better. Andre et al. [9] assessed Spanish economy by taking compromise programming as an analytical tool and studied several Pareto-efficient policies that represent compromises between economic growth and inflation rate. Hashimoto and Wu [10] proposed a data envelopment analysis—compromise programming model for comprehensive ranking including preference voting to rank candidates. Shiau and Wu [11] applied compromise programming to optimize water allocation scheme under multiobjective criteria to minimize the hydrologic alteration and water supply shortages. By combination of fuzzy compromise programming and group decision making under fuzziness, Prodanovic and Simonovic [12] formulated a new multiple criteria multiple expert decision support methodology. However, few have applied CP in pavement management, bridge deck maintenance, or highway asset maintenance management except [13, 14].

This paper applies the concepts of compromise programming and formulates a bilevel model for the resource allocation problem. The first level of the model solves the resource allocation problems for pavement management and bridge deck maintenance, without considering resource sharing between them. The second level of the model solves the resources allocation problems considering resource sharing. The following content is organized as below. Section 2 presents the bilevel optimization model based oncompromising programming. Section 3 is a numerical example applying genetic algorithms to solve the model. The conclusions and recommendations for further study are presented in Section 4.

2. Model

The basic concepts of CP are presented below. Consider the following general multiobjective problem [13, 14]:

$$\begin{aligned} \min \quad & \{f_1(x), f_2(x), \ldots, f_k(x)\}, \\ \text{s.t.} \quad & x \in X, \end{aligned} \tag{2.1}$$

where there are k (≥ 2) objective functions $\{f_i(x),\ i = 1, 2, \ldots, k\}$.

The constraints can be expressed in a general form as $x \in X = \{x \in R^n \mid g_j(x) \leq 0,\ j = 1, 2, \ldots, q;\ h_l(x) = 0,\ l = 1, 2, \ldots, r\}$, where q and r are numbers of inequality and equality constraints, respectively.

If the problem does not have any conflicting objectives, one can apply conventional optimization approaches to obtain a final solution that optimizes all objective functions. However, the objectives are mutually conflicting in many real-world engineering problems. In addition, those objectives can have different measurement scales. Zeleny [4] developed a method that transforms these objectives into a set of comparable scales. He then formulated a new single-objective optimization problem as in (2.2) and showed that the optimal solution from the new problem is a Pareto-optimal solution to the original problem (2.1). Consider

$$\begin{aligned} \min \quad & L_p = \left[\sum_{i=1}^{k} \left(\lambda_i \cdot \frac{f_i(x) - y_i^0}{y_i^0} \right)^p \right]^{1/p}, \\ \text{s.t.} \quad & x \in X, \quad \lambda \in \Lambda. \end{aligned} \tag{2.2}$$

In the Previous expression, y_i^0 is the optimal solution to the original problem containing only the ith objective function $f_i(x)$. p is a parameter satisfying $1 \leq p < \infty$. $\Lambda = \{\lambda \in R^k \mid \lambda \geq 0, \sum_{i=1}^{k} \lambda_i = 1\}$. Let $Z_i(x) = (f_i(x) - y_i^0)/y_i^0$. The meanings of the objective function in (2.2) for different parameter p are discussed in the following.

(a) If $p = 1$, (2.2) can be simplified to (2.3),

$$\begin{aligned} \min \quad & L_p = \sum_{i=1}^{k} |\lambda_i \cdot Z_i(x)|, \\ \text{s.t.} \quad & x \in X, \quad \lambda \in \Lambda. \end{aligned} \tag{2.3}$$

The new objective function, L_p, is a weighted average of all shortest distances of objective values. L_p is called the Manhattan distance.

(b) If $1 < p < \infty$, then (2.2) can be transformed into (2.4)

$$\begin{aligned} \min \quad & L_p = \left[\sum_{i=1}^{k} (\lambda_i \cdot Z_i(x))^2 \right]^{1/2}, \\ \text{s.t.} \quad & x \in X, \quad \lambda \in \Lambda. \end{aligned} \tag{2.4}$$

In this case, the new objective function, L_p, is a weighted summation of geometric distances. When $p = 2$, L_p is a Euclidean weighted distance.

(c) If $p = \infty$, then (2.2) can be transformed into (2.5). In this case, the new objective function, L_p, is a Chebyshev distance as follows

$$\begin{aligned} \min \quad & L_p = \max |\lambda_i \cdot Z_i(x)|, \\ \text{s.t.} \quad & x \in X, \quad \lambda \in \Lambda. \end{aligned} \tag{2.5}$$

Under such transformations, the multiobjective problem in (2.1) has an equivalent single-objective problem, which can be expressed as

$$\begin{aligned} \min \quad & L_p = \left[\sum_{i=1}^{k} (\lambda_i \cdot Z_i(x))^p \right]^{1/p}, \\ \text{s.t.} \quad & x \in X, \quad \lambda \in \Lambda. \end{aligned} \tag{2.6}$$

Earlier approaches to highway infrastructure management were usually developed for single facility management. In this section, we present an optimization model for resource allocation in pavement maintenance. A model for bridge deck maintenance is very similar. The major difference between them is that in the pavement maintenance model, road surface is divided into segments of different lengths, while in the bridge deck maintenance model a bridge deck is divided into different areas. In addition, performance indices are different between the two models.

The objective for the pavement maintenance is to maximize the weighted average surface performance after maintenance. It can be formulated as

$$\max \left\{ \frac{1}{\sum_{i=1}^{I} L_i \times \omega_i} \times \sum_{i=1}^{I} \sum_{a=0}^{A} X_{ia}^0 \times L_i \times PQI_{ia} \times \omega_i \right\}, \tag{2.7}$$

where PQI_{ia} is the pavement quality index of segment i after a type a maintenance, $a = 0, 1, \ldots, A$, L_i is the length of segment i, ω_i is the associated weight for segment i, I is the total number of road segments in the whole network, A is the total number of maintenance types, X_{ia}^0 is a binary decision variable. $X_{ia}^0 = 1$ when a type a maintenance is selected for segment i, and 0 otherwise.

Four sets of constraints are considered in the problem: funding constraints, human resource constraints, equipment constraints, and constraints on road maintenance types.

Funding constraints are expressed in (2.8). It indicates that the total maintenance expenses for all segments must not exceed the total available funds in a specific planning year as follows:

$$\sum_{i=1}^{I}\sum_{a=0}^{A} X_{ia}^{0} \times L_i \times C_{ia}^{p} \leq B_p, \tag{2.8}$$

where C_{ia}^{p} in the above expression is the maintenance expense when a type a maintenance is selected for segment i and B_p is the total available funds for all pavement of the network.

Similar to the funding constraints, human resource constraints can be expressed as

$$\sum_{i=1}^{I}\sum_{a=0}^{A} X_{ia}^{0} \times L_i \times m_{iau}^{p} \leq M_u^{p}, \tag{2.9}$$

where m_{iau}^{p} is the required amount of type u labor when a type a maintenance is selected for segment i and M_u^{p} is the total available amount of type u labor.

The equipment constraints can be expressed as

$$\sum_{i=1}^{I}\sum_{a=0}^{A} X_{ia}^{0} \times L_i \times e_{iak}^{p} \leq E_k^{p}, \tag{2.10}$$

where e_{iak}^{p} is the required amount of type k equipment when a type a maintenance is selected for segment i and E_k^{p} is the total available amount of type k equipment.

It is also assumed that in a maintenance cycle, only one type of maintenance is selected for one segment. Thus, one has the following constraints on road maintenance types:

$$\sum_{a=0}^{A} X_{ia}^{0} = 1, \quad \forall i. \tag{2.11}$$

Typically, highway assets include pavement and bridges. The objective of highway asset maintenance management is to maximum the overall quality of the entire highway network. In this paper, we only consider two types of maintenance: pavement and bridge deck maintenance. Based on the concepts of compromise programming, we formulate a single-objective function as a weighted summation of two distances as below:

$$\max \left\{ \left[\left(\lambda_1 \cdot \frac{\sum_i \left(\sum_a X_{ia} L_i \omega_i PQI_{ia} - \sum_a X_{ia}^{0} L_i \omega_i PQI_{ia} \right)}{\sum_i \sum_a X_{ia}^{0} L_i \omega_i PQI_{ia}} \right)^2 + \left(\lambda_2 \cdot \frac{\sum_j \left(\sum_r Y_{jr} S_j \omega_j CR_{jr} - \sum_r Y_{jr}^{0} S_j \omega_j CR_{jr} \right)}{\sum_j \sum_r Y_{jr}^{0} S_j \omega_j CR_{jr}} \right)^2 \right]^{1/2} \right\}, \tag{2.12}$$

where parameters λ_1, λ_2 represent the weights of pavement and bridge decks, respectively, and ω_i, ω_j are the weights of pavement segment i and bridge deck unit j, respectively; X_{ia} and Y_{jr} are binary decision variables. $X_{ia} = 1$ if a type a maintenance is selected for pavement segment i, and 0 otherwise; $Y_{jr} = 1$ if a type r maintenance is selected for bridge deck unit j, and 0 otherwise. In (2.12), we take p as 2 to avoid cancellation of positive and negative values in the objective function.

The problem has five sets of constraints, which are discussed in the following content.

2.1. Funding Constraints

As the funds for pavement maintenance and bridge deck maintenance can be shared, the total expenses for both pavement and bridge deck maintenance must not exceed the total available funds. Thus, one has the following:

$$\sum_{i=1}^{I}\sum_{a=0}^{A} X_{ia} L_i C_{ia}^{p} + \sum_{j=1}^{J}\sum_{r=0}^{R} Y_{jr} S_j C_{jr}^{b} \leq B, \tag{2.13}$$

where B is the total available funds for entire network maintenance.

2.2. Human Resource Constraints

In highway maintenance, labor can be classified into three groups: personnel only capable of managing pavement, personnel only capable of managing bridge decks, and personnel having both capabilities. Among these three groups, personnel in the third group can be shared between pavement maintenance and bridge deck maintenance. Equations (2.14), (2.15) and (2.16) describe constraints on labor in these three groups, respectively:

$$\sum_{i=1}^{I}\sum_{a=0}^{A} X_{ia} L_i m_{iau}^{p} \leq M_u^{p} \quad u = f+1,\ldots,U \;\; f+1 \leq U, \tag{2.14}$$

$$\sum_{j=1}^{J}\sum_{r=0}^{R} Y_{jr} S_j m_{jrv}^{b} \leq M_v^{b} \quad v = f+1,\ldots,V \;\; f+1 \leq V, \tag{2.15}$$

$$\sum_{i=1}^{I}\sum_{a=0}^{A} X_{ia} L_i m_{iau}^{p} + \sum_{j=1}^{J}\sum_{r=0}^{R} Y_{jr} S_j m_{jrv}^{b} \leq M_u^{p} + M_v^{b} \quad u = v = 1,\ldots,f, \tag{2.16}$$

where f is the total number of labor types that can be shared between pavement maintenance and bridge deck maintenance; U is the total number of labor types that can only be used for pavement maintenance; V is the total number of labor types that can only be used for bridge deck maintenance.

2.3. Equipment Constraints

Equipment resources can also be classified into three groups: equipments only usable in pavement maintenance, equipments only usable in bridge deck maintenance, and equipments usable in both pavement and bridge deck maintenance. Equations (2.17), (2.18), and (2.19) describe constraints on equipment in these three groups, respectively:

$$\sum_{i=1}^{I}\sum_{a=0}^{A} X_{ia} L_i e_{iak}^{p} \leq E_k^p \quad k = g+1, \ldots, K \;\; g+1 \leq K, \tag{2.17}$$

$$\sum_{j=1}^{J}\sum_{r=0}^{R} Y_{jr} S_j e_{jrl}^{b} \leq E_l^b \quad l = g+1, \ldots, L \;\; g+1 \leq L, \tag{2.18}$$

$$\sum_{i=1}^{I}\sum_{a=0}^{A} X_{ia} L_i e_{iak}^{p} + \sum_{j=1}^{J}\sum_{r=0}^{R} Y_{jr} S_j e_{jrl}^{b} \leq E_k^p + E_l^b \quad k = l = 1, \ldots, g, \tag{2.19}$$

where g is the total number of equipment types that can be shared, K is the total number of equipment types that can be used in pavement maintenance, and L is the total number of equipment types that can be used in bridge deck maintenance.

2.4. Constraints on Maintenance Types

In each maintenance cycle, it is assumed that only one type of maintenance can be selected for a pavement segment or bridge deck unit. Hence, we have additional constraints as follows:

$$\sum_{a=0}^{A} X_{ia} = 1 \quad \forall i,$$
$$\sum_{r=0}^{R} Y_{jr} = 1 \quad \forall j. \tag{2.20}$$

2.5. Least Performance Constraints

From the transformations of objective functions in compromise programming, it is noted that when parameter p is an even number, the value within the parentheses in (2.12) can be either positive or negative. When this value becomes negative, highway asset maintenance management will not achieve any benefits. Hence, we have additional constraints that the performance of highway infrastructure under resource sharing must exceed or at least equal that without resource sharing. Such constraints can be presented in the following:

$$\sum_{i=1}^{I}\left(\sum_{a=0}^{A} X_{ia} L_i \omega_i PQI_{ia} - \sum_{a=0}^{A} X_{ia}^{0} L_i \omega_i PQI_{ia}\right) \geq 0,$$
$$\sum_{j=1}^{J}\left(\sum_{r=0}^{R} Y_{jr} S_j \omega_j CR_{jr} - \sum_{r=0}^{R} Y_{jr}^{0} S_j \omega_j CR_{jr}\right) \geq 0. \tag{2.21}$$

Table 1: Human resource demands for different types of pavement maintenance.

Maintenance types	Labor Demands (Man-days)			
	Technical chiefs	Drivers	Ordinary workers	Equipment operators
No maintenance	0	0	0	0
Minor maintenance	1	1	1	2
Moderate maintenance	1	3	3	4
Major maintenance	2	5	6	7

Table 2: Productivities for types of maintenances and types of road facilities.

Highway types	Productivities (Lane-km/Day)			
	No maintenance	Minor maintenance	Moderate maintenance	Major maintenance
State highways	0.0	5.1	2.3	0.8
Provincial highways	0.0	6.7	3.5	1.4
County roads	0.0	8.5	4.2	2.1

3. Numerical Analysis

In this numerical example, the highway network consists of four types of facilities: 16.7 lane-km of state highways, 30.7 lane-km of provincial highways, 59.6 lane-km of county roads, and 20.3 lane-km of bridges. For each pavement unit or bridge deck unit, one can choose from the following four options: major maintenance, moderate maintenance, minor maintenance, and no maintenance. The resources (e.g., funds, human resources, equipments) amounts required for different maintenance options and for different facility types are assumed to be known. It is also assumed that the information on infrastructure quality after different types of maintenance is available for analysis.

Table 1 lists the amounts of human resources required in different types of maintenance. Table 2 shows the productivities for different maintenance types against facility types. In addition, the model requires other information such as unit maintenance expense, equipment allocation, before-and-after facility quality, interest rates, total available funds, and other resources, least performance requirements for each facility unit, and variations of traffic volumes. The input information for each bridge deck unit is similar to that for a pavement segment.

Although the highway network is not large, the space of all feasible solutions to the problem is very large, and complete enumeration is computationally infeasible as a method of finding the optimal solution. In this paper, we apply genetic algorithms (GA) to search for the optimal solution.

A chromosome in GA is a string of 0-1 numbers. Here we use a combination of two digits to represent various maintenance types. For instance, “00” stands for “no maintenance”, while “01,” “10,” and “11” stand for minor, moderate, and major maintenances, respectively.

In this example, a blue cell represents a pavement segment, and a green cell represents a bridge deck segment. A chromosome, that is, a feasible solution to the model, consists of 10 fractions. Each fraction represents a one-year pavement and bridge deck maintenance plan, see Figure 1. As for any specific fraction, there are 2 parts, blue one and green one. The blue part indicates pavement maintenance plan and the green part corresponds to bridge deck maintenance plan for a given year.

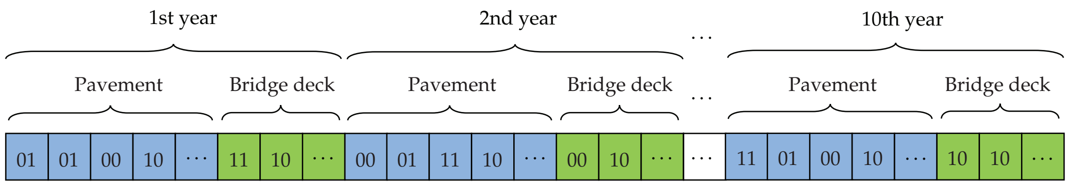

Figure 1: GA code for the solution.

Table 3: Human resources utilization in highway maintenance with and without resource sharing (working days).

Labor types	Maintenance without resource sharing			Maintenance under resource sharing	Total available human resources
	Pavement	Bridge deck	Total		
Technical chiefs	4.7	8.6	13.3	21.7	26.0
Drivers	8.3	15.9	24.2	35.0	35.0
Ordinary workers (1)	8.3	0.0	8.3	16.1	30.0
Ordinary workers (2)	0.0	19.5	19.5	18.9	30.0
Equipment operators (1)	13.0	0.0	13.0	28.3	40.0
Equipment operators (2)	0.0	18.3	18.3	18.9	30.0

There are two steps in solving the problem. At the first step, we obtain the optimized solutions for pavement maintenance and bridge deck maintenance, without considering resource sharing. The second step uses the results from the first step as input and generates the final solution to the resource sharing problem.

The GA parameters are determined with some preliminary analyses. In solving the pavement maintenance problem at the first step, the population size and iteration number, mutation rate are set at 500, 600, and 0.02, respectively. In solving the bridge deck maintenance problem, the population size, iteration, mutation rate to 300, 200, and 0.02, respectively. At the second step computation (with resource sharing), the values of these 3 parameters are set at 500, 2000, and 0.03, respectively.

Table 3 shows the human resources utilization in the base year for maintenances with and without resource sharing. It is apparent that the utilization efficiency for the six types of labors is increased, respectively. Table 4 compares equipments utilization in maintenances with and without resource sharing.

Figure 2 indicates the performance changes of pavement and bridge decks after maintenance. It can be easily seen that for all planning years, both pavement performance and bridge deck performance are improved with resources sharing.

4. Conclusions

The objective of highway asset maintenance management is to maximize the overall conditions of the highway system after maintenance with limited resources. This is achieved through integrated management for different types of highway facilities. The paper presents a new approach for optimal allocation of highway maintenance resources based on compromise programming. With the concepts of compromise programming, one can consider the relative importance of different highway facilities by introducing associated weights into the objective function. A bilevel model has been developed to analyze the

Table 4: Equipments utilization in highway maintenance with and without resource sharing (Working Days).

Equipment types	Maintenance without resource sharing			Maintenance under resource sharing	Total available equipments
	Pavement	Bridge deck	Total		
Dual-use mini vans	4.7	7.4	12.1	21.7	25.0
Backhoe/loaders	3.6	2.4	6.0	3.8	11.0
Pavement saws	2.9	8.6	11.5	19.8	23.0
Grinders	2.9	9.7	12.6	19.8	26.0
Compressors	6.5	1.2	7.7	14.2	18.5
Scrapers	1.8	0.0	1.8	1.9	5.0
Welding torch	0.0	1.2	1.2	0.0	3.0
Vibrating compactors	0.0	8.6	8.6	9.5	10.0
Cement mixers	0.0	1.2	1.2	0.0	3.2

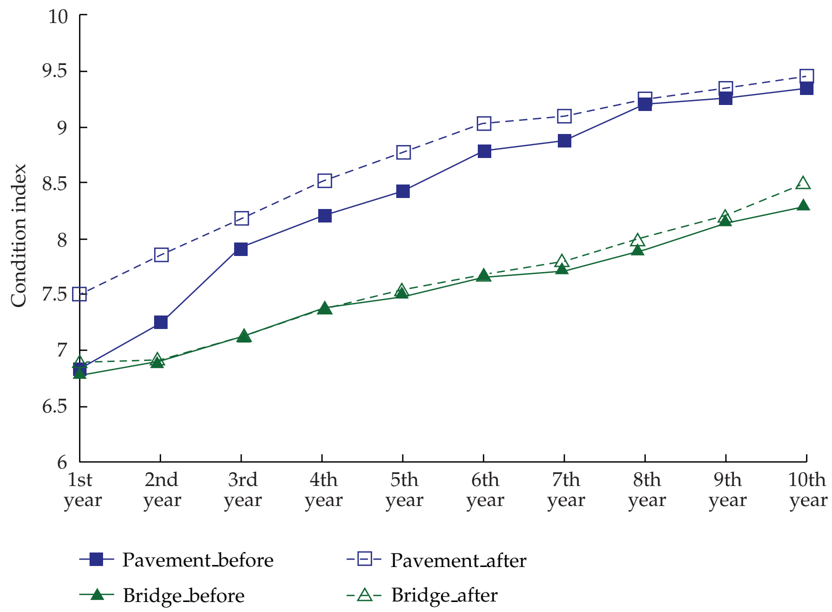

Figure 2: Comparison of condition changes for pavement and bridge-decks with and without resource sharing.

resource allocation problem in pavement and bridge deck maintenance. Two scenarios in maintenance activities are analyzed: first without and then with sharing of resources between pavement maintenance and bridge deck maintenance. With a robust GA searching for an optimal solution to the problem, it is found that the performance of pavements and bridge decks improves significantly under resource sharing. The maintenance resources (e.g., funds, labor, and equipment) are utilized more efficiently in the resource-sharing scenario. The results of experimental analyses clearly show the promising features of the model in solving complex resource allocation problems in highway maintenance management. The method developed in this paper is useful to highway agencies in their decision-making activities such as developing maintenance programs, budgeting, and resource allocation.

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References

[1] FHWA, Asset Management Primer, Office of Asset Management, FHWA, US DOT, 1999.

[2] FHWA, Annual Report 2001, Office of Asset Management, US DOT, 2001.

[3] P. L. Yu, “A class of solutions for group decision problems,” *Management Science*, vol. 19, no. 8, pp. 936–946, 1973.

[4] M. Zeleny, “Compromise Programming,” in *Multiple Criteria Decision Making*, J. L. Cochrane and M. Zeleny, Eds., pp. 262–301, University of South Carolina, Columbia, 1973.

[5] Z. Lounis and M. Z. Cohn, “An engineering approach to multicriteria optimization of bridge structures,” *Computer-Aided Civil and Infrastructure Engineering*, vol. 10, no. 4, pp. 233–238, 1995.

[6] M. Zarghaami, “Integrated water resources management in Polrud irrigation system,” *Water Resources Management*, vol. 20, no. 2, pp. 215–225, 2006.

[7] L. Diaz-Balteiro, R. Voces, and C. Romero, “Making sustainability rankings using compromise programming. An application to European paper industry,” *Silva Fennica*, vol. 45, no. 4, pp. 761–773, 2011.

[8] M. Amiri, M. Ekhtiari, and M. Yazdani, “Nadir compromise programming: a model for optimization of multi-objective portfolio problem,” *Expert Systems with Applications*, vol. 38, pp. 7222–7226, 2011.

[9] F. J. Andre, M. A. Cardenete, and C. Romero, “Using compromise programming for macroeconomic policymaking in a general equilibrium framework: theory and application to the Spanish economy,” *Journal of the Operational Research Society*, vol. 59, no. 7, pp. 875–883, 2008.

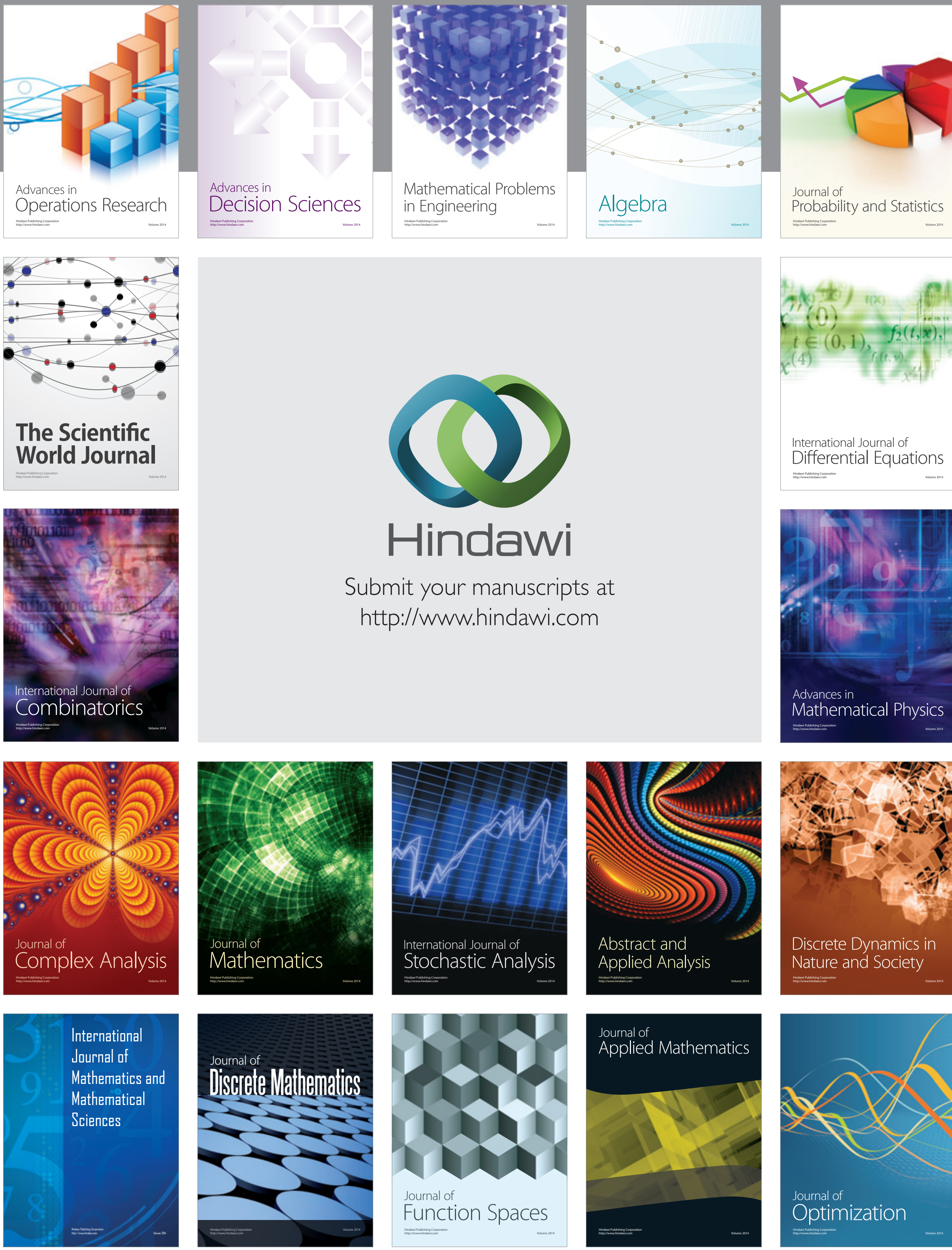
[10] A. Hashimoto and D.-A. Wu, “A DEA-compromise programming model for comprehensive ranking,” *Journal of the Operations Research Society of Japan*, vol. 47, no. 2, pp. 73–81, 2004.

[11] J. T. Shiau and F. C. Wu, “Compromise programming methodology for determining instream flow under multiobjective water allocation criteria,” *Journal of the American Water Resources Association*, vol. 42, no. 5, pp. 1179–1191, 2006.

[12] P. Prodanovic and S. P. Simonovic, “Fuzzy compromise programming for group decision making,” *IEEE Transactions on Systems, Man, and Cybernetics A*, vol. 33, no. 3, pp. 358–365, 2003.

[13] H. Xiong, “Optimal allocation of highway maintenance resources based on compromise programming,” *Journal of Tsinghua University*, vol. 46, no. 12, pp. 1961–1964, 2006 (Chinese).

[14] H. Xiong, “Multiobjective optimization of pavement management using compromise programming,” *Journal of Beijing Institute of Technology*, vol. 26, no. 9, pp. 793–797, 2006 (Chinese).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