Multi-objective Optimization for Roadway Maintenance Engineering Based on ev-MOGA

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Abstract. The performance of roadway maintenance is a highly correlated factor on national socio-economic issues. Roadway maintenance work is a complex task, involving market game, engineering, planning and scheduling. Taking such aspects as quality, schedule and cost into account, this paper develops a multi-objective roadway maintenance system, in which ev-MOGA is adopted to optimize the decisions concerning roadway maintenance. The experimental results can provide a references for fuzzy multi-objective optimization (MOP) problems.

1. Introduction
The increasing global awareness of sustainability and climate change (CC) has motivated an ever-growing number of transportation agencies to embrace the principles of sustainability in pavement management practices[1]. Santos et al.[2]present the development of a decision-support system framework for pavement management that aims to enhance the sustainability of the road pavement maintenance. The Multi-Objective Decision-Aid Tool (MODAT) uses a multi-objective deterministic section-linked optimisation model with different possible goals and the deterministic pavement performance model used in the AASHTO flexible pavement design method[3]. Ji[4] taking advantage of decision-making method of multi-objective and multi-attribute in mathematical programming, determines the sorting of road maintenance based on the synthesis comparison of smoothness and damage condition as well as pavement skid-resistant.

With the expansion and application of image technology, internet, cloud computing technology and internet of things technology, the application performance of pavement management system is further improved. However, there still exists a variety of constraints on the system management complexity, mechanical property of roadway’s section, maintenance planning and road network structure, etc. which make it difficult to reconcile all the objectives. Schedule, cost and quality is the major control objectives. The coordinating of the three requires plentiful support work. The engineering management and control is much more complicated especially in the case of changing external environment. Based on ev-MOGA, this paper aims to design the roadway maintenance quality-cost-time-oriented multi-objective control system.
2. Methods

2.1 Technical Indicators of Roadway Maintenance
As for long-term maintenance planning, due to the uncertainty of performance prediction and maintenance program, this paper aims at the pavement performance maintenance of a given year. However, the pavement performance prediction value is only as a reference. In effect, it is the actual data based on the pavement detection in the previous year applied to the evaluation and maintenance requirement analysis. According to the relevant standard specification of roadway pavement, the pavement basic data that needs to be detected includes international roughness index (IRI), damage rate (DR), pavement deflection, and sideways force coefficient (SFC). On the basis of pavement current condition data, we need to respectively compute the riding quality index (RQI), pavement condition index (PCI), skidding resistance index (SRI), pavement structure strength index (PSSI) of each line and section, and computational synthetic pavement quality index (PQI). Generally, it is suggested that the effect evaluation of roadway maintenance program mainly references Pavement Quality Index (PQI).

Through pavement detection and multiple index calculation, forming a comprehensive analysis of roadway maintenance requirement and general operational status of road network from both the macro and micro level is the basis of pavement maintenance multi-objectives optimization. It also provides evidence for some issues that concerns much about multi-objectives like maintenance priority, funds distribution optimization, technical program and other issues.

The maintenance decision requires the pavement evaluation and prediction as for reference, and the evolution of pavement has different decay equation. The pavement performance decay equation have been studied both in domestic and foreign. The pavement performance decay equation can be basically divided into S-type decay equation and exponential decay equation, etc. The elemental pavement performance decay equation is defined as: 

\[ PQI = PQI_0 e^{-\alpha t} \]

Where \( PQI_0 \) is the initial value of \( PQI \) taken as 100 generally. \( T \) refers to Pavement Operation Duration, \( \alpha \) and \( \beta \) refer to regression coefficient.

2.2 Multi-Objective Optimization Model for Roadway Maintenance Based on ev-MOGA
Ev-MOGA is an elitist multi-objective evolutionary algorithm based on the concept of epsilon dominance. Ev-MOGA tries to obtain a good approximation to the Pareto Front in a smart distributed manner with limited memory resources. It also adjusts the limits of the Pareto front dynamically. This paper considers roadway maintenance decision from the three objectives of quality, schedule and cost and forms the T-C-Q objective function group.

\[
\begin{align*}
\text{min} \quad & T = \text{max} \left\{ \sum_{i,j \in \mathcal{L}} t_{ij} \right\} \\
\text{min} \quad & C = \sum_{i,j \in \mathcal{L}} \left[ c'_{ij} + \alpha_{ij} (t''_{ij} - t'_{ij}) \right] + c''_{ij} - c'_{ij} \left( \frac{t''_{ij} - t'_{ij}}{t''_{ij} - t'_{ij}} \right) \\
\text{max} \quad & Q = \frac{100}{1 + 0.0185 e^{-0.3975 t}} + (100 - 15 DR^{0.8 t}) + \left( \frac{100 - SRI_{\text{max}}}{1 + 266 e^{-0.315 \theta}} + SRI_{\text{min}} \right) + \left( 1 + 15.7 e^{-0.15 \theta} \right)
\end{align*}
\]

In above equations, \( t_{ij} \) means the duration between adjacent steps, \( c'_{ij} \) is direct cost, \( c''_{ij} \) is indirect cost, \( t''_{ij} \) is continuous duration, \( t'_{ij} \) is possible minimum duration, \( c''_{ij} \) and \( c''_{ij} \) are corresponding indirect cost. IRI \( \in [1.4,1.5] \), the unit is m/km, SFC \( \in [40,50] \), DR \( \in [0.001,0.0015] \), \( lR, lD \in [0.01,0.012] \), the unit is mm, \( a_i \) is a marginal increase factor, \( \in (0,1) \).

Where schedule is measured in months, cost is in thousand, and quality is a dimensionless quantity. In this paper, \( \theta \) in ev-MOGA algorithm is a kind of hybrid multi-attribute parameters. Where \( t \) is set to \( t_1, c \) to \( t_2 \), IRI to \( t_3 \), DR to \( t_4 \), SRI to \( t_5 \), SFC to \( t_6 \), \( lR \), \( lD \) to \( t_7 \). Since there is a complete set of technical reference standards for roadway maintenance program and the management of tendering and bidding is strict, thus, for the parameter \( t_3\rightarrow t_6 \). Fine tuning is allowed within the error range of roadway maintenance standard. The major variable factors are \( c \) (cost) and \( t \) (duration).
3. Case Study

Part of an roadway maintenance engineering was cited as a case to illustrate the application of the above model. Because the maintenance engineering are almost outsourced and both the maintenance technology and engineering planning adopt formatting management, the specific technical operations will not be considered in this paper. The primary issue revolves around the T-C-Q performance generated by the flexible variable factors in the engineering, such as the schedule arrangement of the engineering. It is supposed that steps of A, B and C start operating separately at $t_i$, $t_j$ and $t_k$, and the schedule corresponds to $T_i$, $T_j$, $T_k$. Appropriate changes are available. There is a certain roadway maintenance engineering, measuring 6,588 meters in length. To test the method this paper studies on, a 1,000m long roadway as a part of the engineering will act as the test object. We assume that the whole engineering daily average indirect cost of 1,000 is ¥1/day. According to the budget plan and network diagram, the maximum duration is 210 days while the minimum duration is 156 days. The maximum cost and minimum cost is 21.0055 million and 18.0379 million respectively. The worst quality of each process is set as 0.80-0.90. Through Matlab, in the 38th cycle, the optimal solution of single objective is respectively 1.00235, 0.0000625277 and -11.726, in which the quality is transformed from max to min. Therefore, the optimal solution is 11.726. The optimal solution of single objective satisfies the Pareto conditions (Figures 1, 2 and 3), but the optimal solution of multi-objective is uncertain.

![Figure 1. Schedule Evolution](image1)

![Figure 2. Cost Evolution](image2)
This case chooses the optimal solution of single objective as the optimal ideal point and the shortest distance as a global multi-objective optimal solution.

The multi-objective optimal value of roadway maintenance by calculating the distance is (11.7641, 1.50992, -11.5182). Compared with the ideal point, it is found out that the schedule stress does not achieve the optimized multi-objective and it is unrealistic to reduce cost. However, the construction is able to remain a pretty high level with punctual duration and controllable cost. The calculation results are much effective with the ev-MOGA algorithm due to the Box setting of the optimized searching range, which is capable of handling the sudden emergency such as the weather and traffic in the roadway maintenance multi-objective decision.

4. Conclusion
Roadway maintenance is of strategic significance to the development of the city. The performance of roadway maintenance from the three objectives of schedule, cost and quality is examined. Development of the roadway maintenance multi-objective decision model based on ev-MOGA is able to solve problems efficiently and deal with changeable factors reasonably. The model requires much parameters setting. However, due to the evolutionary mechanism, the calculation results are less sensitive to the parameter input. The Pareto optimal solution of great convergence and diversity generated by simulation offers a significant reference to the roadway maintenance program and other similar fuzzy multi-objective optimization problems in other fields.

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