Carbon dioxide minimization in large-scale pavement network maintenance planning

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ABSTRACT

Choosing an appropriate strategy in order to maintain pavements has become a significant concern. Recently, pavement agencies tackle large-scale networks, which makes the problem complicated. To prevail in this complexity, utilizing metaheuristic algorithms can be an ideal approach. By increasing the dimension of the problem, the competency of metaheuristic algorithms is by far enhanced. To this end, the water cycle algorithm is applied to solve the problem. In this investigation, two models, including single objective optimization and multi-objective optimization, are taken into consideration. In the single-objective model, the minimization of the network International Roughness Index (IRI) is considered as the objective function. In multi-objective optimization modeling, minimization of the network International Roughness Index and embodied CO2 emission are taken into account simultaneously. Furthermore, a new constraint is considered in the model, which leads to restricting the budget fluctuation in different years of the analysis period. A network, including 79 segments, is the case study of this investigation. The results reveal that the water cycle algorithm is highly qualified to solve the pavement maintenance and rehabilitation problem. According to results, multi-objective optimization reduces the CO2 emission by 47.2% compared with single-objective modelling. Furthermore, the variation of minimum and maximum cost is less than 20% in the planning horizon.

KEYWORDS

Water cycle algorithm, Pavement management system, Large-scale networks, Environment, Optimization

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1. Introduction

Transportation infrastructure plays a pivotal role in the economy, transporting people and goods. Accordingly, enhancing the condition of pavements has been an immense concern. Pavement management system (PMS) is a strategic tool to preserve the mentioned infrastructures. The PMS aims to help the decision-makers to select the appropriate maintenance and rehabilitation activities for pavement sections [1].

Different techniques have been applied to solve the pavement M&R optimization problem. By increasing the number of sections in the network and by consideration of various criteria, the complexity of the M&R optimization problem increases exponentially, and the problem converts to an NP-hard problem. In this regard, the application of metaheuristic algorithms may be the best option [2].

Khavandi Khiavi employed a genetic algorithm (GA) to present an optimal M&R plan for a network, including 17 sections, and the result indicated that GA is highly qualified to find the optimal solutions to M&R optimization problems [3].

Environmental issues can not be overlooked in these problems. The transportation sector is the second-largest source of greenhouse gas emissions. Approximately 30% of global air pollution and 25% of fossil fuel consumption are the contributions to the transportation sector. Therefore, CO_2 emission should be considered in M&R optimization problems.

2. Methodology

The international roughness index (IRI) is considered the performance indicator to analyze the condition of pavements. Two approaches, including multi-objective modeling and single-objective modeling, are taken into account. The multi-objective approach considers pavement condition and CO_2 emission simultaneously. The single-objective approach considers only the pavement condition.

2.1. Problem modeling

The problem formulation are indicated in Eq. (1) to Eq. (6).

$$minZ = \sum_{i=1}^{n} (IRI_{i,x} - IRI_{ideal})^2 \qquad (1)$$

$$minZ = \sum_{i=1}^{n} CO_2 \qquad (2)$$

$$\frac{\sum_{i=1}^{n} IRI_{i,y} \times Area_i}{Area_T} \leq Ideal \;\; , \forall y \in \{1,2,\ldots,x\} \qquad (3)$$

$$IRI_{i,y} \geq IRI_{min} \; \forall i \in \{1,2,\ldots,n\}, \forall y \in \{1,2,\ldots,x\} \qquad (4)$$

$$\sum_{i=1}^{n} Cost_{i,y} \leq Budget_y \;\; \forall y \in \{1,2,\ldots,x\} \qquad (5)$$

$$MaxCost_y - minCost_y \leq A \times MaxCost_y \; \forall y \in \{1,2,\ldots,x\} \qquad (6)$$

Eq. (1) and Eq. (2) are objective functions of the multi-objective approach. Single-objective modeling considers Eq. (1) the objective function of the problem. The Eq. (1) improves the condition of pavements and Eq. (2) minimizes the total CO_2 emission generated during the analysis period.

2.2. Algorithm process

As previously mentioned, large-scale multi-objective M&R optimization problems are NP-hard problem. To this end, a robust metaheuristic algorithm called “water cycle algorithm” is employed to plan the M&R activities for the case study of this investigation.

3. Case study

The case study of this investigation includes 79 flexible pavement sections with different lengths. The average network IRI should be lower than 3.5 m/km all the time in the analysis period. IRI_{ideal} is considered 2.2 m/km. The IRI of sections is ranged from 2.09 m/km to 6.14 m/km. The analysis period is considered five years, and in this period, the annual cost is not allowed to fluctuate more than 20%. The annual budget is 12.2 million dollars. The M&R activities are shown in Table 1 [4–9].

Table 1. M&R activities, their improvements, costs, and emissions

M&R activity	IRI drop (m/km)	Unit cost ($/m^2)	Unit CO_2 emission (kg/m^2)
Do nothing	0	0	0
Crack sealing	0.27	1.06	0.11
Chip seal	0.72	4.9	0.4
Thin hot mill overlay	1.44	23.37	6.91
Milling and 7.5cm hot mill overlay	2.2	47.84	8.5

Milling and 7.5cm hot mill overlay	3	63.79	13.11

4. Results

The cost of single-objective and multi-objective approaches offered by WCA is indicated in Fig 1. As can be seen from the results of Fig 1, the single-objective approach requires 52.7 million dollars and the multi-objective approach needs 38.9 million dollars in the 5-year planning horizon. Hence, it can be theorized that CO_2 consideration reduces the required cost.

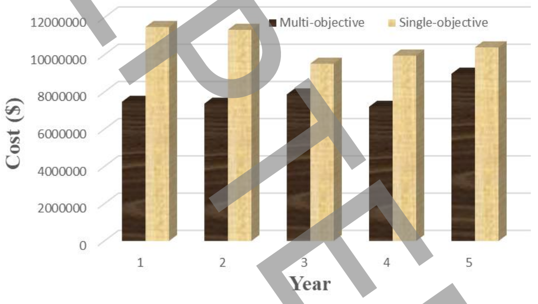

Fig 1. The cost of single-objective and multi-objective approaches

The IRI of the network in the planning horizon is illustrated in Fig 2. Based on the results presented in this figure, the condition of the network in both approaches is approximately the same. However, the condition-based performance of the single-objective approach could be a bit better than that of the multi-objective approach.

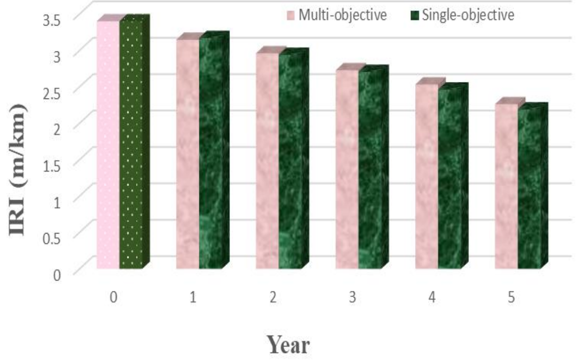

Fig 2. The network IRI during the time

Fig 3 provides information about the content of CO_2 emitted in the analysis period. As can be perceived from the outcomes of this figure, the single-objective method emits 10.6 million kg CO_2 in the analysis period, while the multi-objective method reduces this value by 5 million kg. That is to say, the multi-objective approach can reduce CO_2 emission by 47.1%, which is significant.

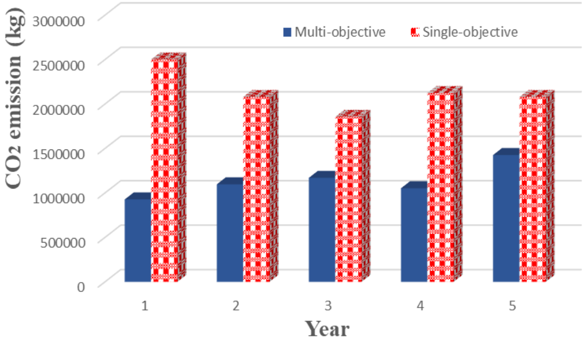

Fig 3. The CO2 emitted in different years by single-objective and multi-objective approaches

5. Conclusions

The multi-objective approach outperforms the single-objective model based on the required cost and total CO_2 emission. Nonetheless, the performance of the single-objective model according to pavement condition is a bit better than that of multi-objective modeling.

6. References

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