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NOVEL ASSET MANAGEMENT FRAMEWORK FOR ROAD MAINTENANCE

Mohammadi, Alireza[1, 5], Igwe, Charles[1], Amador-Jimenez, Luis[1], and Nasiri, Fuzhan[1]
[1-4] Concordia University, Canada
[5] alireza.mohammadi@concordia.ca

Abstract: As assets begin to deteriorate either due to age or additional demands based on urbanization, it becomes imperative to renovate or replace them to ensure that they continue to deliver the level of service required by the end user. Asset management, therefore, becomes a very important consideration in the development of nations. However, there is another key factor worthy of consideration and this is based on the principles of lean construction. According to the lean construction paradigm, to increase value to the end user in any project, especially projects in urban areas where the effect of delays is more noticeable and profound due to the number of people requiring the use of these assets, waste must be eliminated or reduced to the barest minimum and doing this requires conformance to five major principles. Classical practices in the asset management domain; however, have not embraced the lean construction paradigm in road maintenance or rehabilitation plan. This paper suggests a framework to establish a formalized road management procedure with a focus on the principles of lean construction for avoiding non-value activities. To validate the proposed approach, a case study project is tested. The results of the case study revealed that by using the developed model, a 20% reduction in the project budget can be achieved while still ensuring that the required level of service is maintained. Based on this developed model, roads and other infrastructure decision-makers will be able to make better asset management plans that will ensure that project stakeholders including the end users get better value for their money and time.

1 INTRODUCTION

The competition for resources required to promote economic development and cater for the effects of urbanization has made it imperative to ensure that whatever budget or resources are allocated to projects be adequately utilized to provide value for time and money. One of the precursors to development is the availability of good and well-maintained road networks to meet the demands of road users and reduce inconveniences that may arise from bad and poorly maintained roads. The decision on which road to select for maintenance is not usually an easy one as there are several factors to consider including the selection of which asset (e.g. which road segments in a highway) requires the most intervention, the choice of the maintenance or rehabilitation actions, and the best time for actions. The aforementioned factors are mainly bothered by finance.

There is a rich literature existing in terms of Road Asset Management (RAM) efforts and several types of research have been conducted to provide recommendations and solutions aimed at improving the performance and safety of road systems subject to budgetary constraints. The traditional planning approach for providing interventions in RAM involves three distinct phases of planning in strategic level, translating this plan into tactical and operational projects, and finally implementation through assigning the plan to construction teams.

In the planning phase, decision-making models of cost-effectiveness analysis or mathematical optimization could be applied to find the optimum treatment/intervention actions across competing alternatives (trade-off) which is mostly done in a long-term horizon. Next phase involves the implementation of the selected intervention actions which is typically achieved through agencies outsourcing the work to be performed. However, before outsourcing, it is important to convert long-term (strategic) plan into tactical and operational projects which is less discussed and elaborated topics in the literature and possibly producing wasting values and disruption of services (Faghih-Imani and Amador 2013). Coordination could be applied by asset managers in this phase based on expert judgments; however, the feasibility of the plan lies in its ability to ensure the avoiding unnecessary costs (mobilization and demobilization) when carrying out the road maintenance actions plan as well as minimization of the disruption that will be suffered by the road users.

1.1 Lean Construction Principles

The focus of the lean paradigm is the elimination of wastes to promote the value. According to Fewings (2013), the lean thinking goes beyond the elimination of waste and extends its application to value delivery. Womack and Jones (2010) add further that lean thinking creates a means for specifying the value, differentiates value adding from non-value adding activities and helps in the sequential arrangement of value-adding activities. There are five major principles of lean thinking and these include value, value stream, flow, pull and continuous improvement. These principles are focused on the reduction in the share of non-value adding activities, reduction in variability and lead time, increased flexibility, transparency and simplicity of operations. Applying the lean construction paradigm to RAM ensures that stakeholders get value for their time and money by ensuring the proper selection of intervention measures for road assets, prioritizing the intervention measure to be applied while ensuring that intervention activities flow seamlessly from one selected road section to another.

1.2 Common Wastes in Road Asset Management (RAM)

The principles of lean thinking can be applied to RAM to facilitate value for main stakeholders including the transportation agencies, the road maintenance contractors, and the end users. From a lean perspective, asset manager could look for wasted value in the process of reinvestment for Maintenance, Rehabilitation, and Replacement (MRR). One source which contributes to wasting is identified in the classical process including those costs are involved to repetitive mobilization and demobilization. Thus, in the planning step, decision-maker could pick the alternatives in which minimize these kinds of costs in the construction phase. Implementing the lean idea during the planning phase in RAM helps to improve MRR plan for the construction phase by ensuring the elimination of non-value adding activities as will be demonstrated later in the case study section. Figure 1 is developed to present applying lean perspective in road asset management.

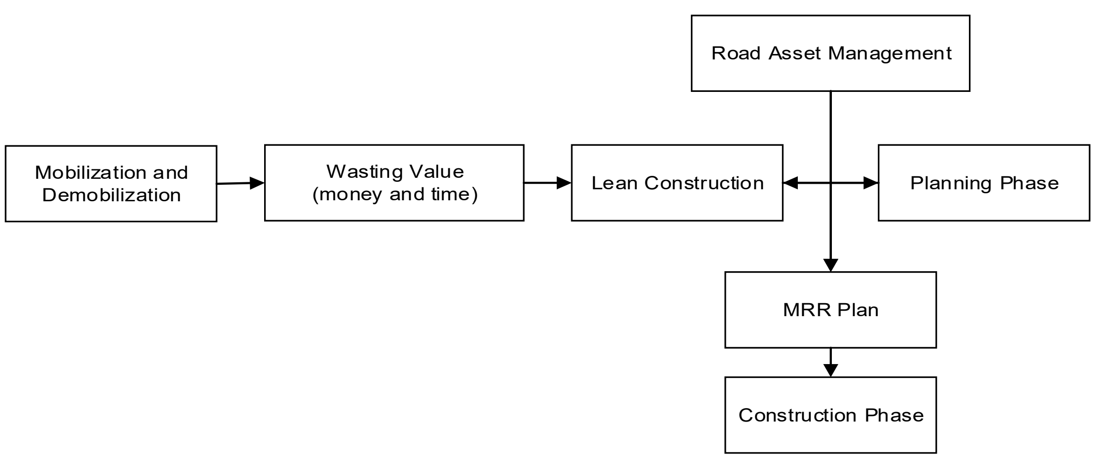

Figure 1: Addressing lean construction in RAM

1.3 Background

Mobilization and demobilization are common wastes usually experienced when performing road maintenance works for separate road segments geographically distributed along the same road network. Studies conducted by Amador and Magnuson (2011) and Osman (2016) generated coordinated programs of maintenance and replacement works for different types of infrastructure in the same location to avoid wastes, disruptions, and repetition. Attempts have been made by researchers to reduce this time and money waste. Faghih-Imani and Amador (2013) developed a framework with specific distance and temporal rules to coordinate road maintenance projects; however, clustering alternatives is still done in the separate step by decision-maker based on designed plan doubting to achieve an optimal solution. Galenko et.al. (2015) conducted a study to optimize created construction plan by modifying the maintenance schedule while respecting coordination. However, this study had some notable shortcomings, the developed model addressed coordination of the road segments for repairs by fast-tracking or postponing treatment actions. However, this method does not ensure acceptable and safe performance levels for all segments in each year. Also, the user cost associated with each project as a part of the decision-making process was also not defined.

Several types of research have focused on addressing coordination during the construction phase as a means of minimizing disruptions. Theiss et al. (2016) developed a guideline for the U.S. federal highway administration (FHA) to minimize work zone mobility impacts in the construction phase. Lee (2005) tested different construction closure times of weekday and weekend to find the lowest cost scenario for both user and agency. Morgado (2014) proposed a model for work zone planning in pavement rehabilitation to integrate costs, duration, and user effects and select the best alternative minimizing disruption. Oh et al. (2011) developed a scheduling framework to minimize road project disruptions while using existing transportation networks; however, this model may work in urban road networks with enough alternatives. Addressing coordination is typically neglected during the planning stage, which may give more flexibility. In the traditional planning models RAM, plan alternatives are analyzed through several indicators of costs, level of service, safety, gas emission and user costs. However, user costs mostly reflects the relationship between road conditions and costly attributes for users (such as car maintenance costs or fuel consumption) while delays caused when road sections are under maintenance works is often neglected in decision-making (Santos, 2005 and Moreira 2017). It might be resulted by difficulty in data collection and quantification.

The state of the art shows that there is a gap in the literature providing transportation agencies with the opportunity for avoiding time and money waste during the planning and construction phase. This paper suggests a framework to establish a formalized asset management procedure based on lean construction principles (eliminating waste to enhance value) in road management process. A decision-making model will be developed to provide guidance to road agencies in arriving at the optimum choice of asset MRR plan. Based on the result of the study, decision-makers will be able to make more efficient asset management decisions addressing coordination that will ensure project stakeholders get better value for their time and money.

2 METHODOLOGY

2.1 Mobilization and Demobilization

As a repetitive process, road agencies need to select several roads each year for maintenance and rehabilitation purposes. This kind of modeling has been advanced through time mostly from planning rather than construction point of view. Mature frameworks, objectively distribute available budget in order to maximize performance and safety. However, from a practical point of view, some factors may impact construction quality and cost. One time-consuming and costly step in any construction activity is the mobilization and demobilization of personnel/machinery and contractors always try to avoid repeating mobilization as it is a waste of time and very costly phase. The results from road management planning is commonly a bunch of segments geographically distributed along the road network, which is not necessarily near or next to each other. Meanwhile, transit agencies, particularly on low and medium-size roads, often avoid working with several contractors for a specific road. Therefore, the contractor must mobilize and demobilize several times to implement requested interventions and this increases the share of non-value activities with an attendant decrease in actual value-adding activities. In this study, the developed model tries to improve the overall performance of each road while respecting the coordination between the plan and the different road sections requiring intervention. By increasing the number of side by side segments in each year planning, this fixed cost could be decreased while time is saved too.

2.2 Mathematical Approach

The budget limitation is a common obstacle in pavement management. Transit agencies usually concentrate on utilizing the bulk of the budget on respecting safety and performance thresholds while utilizing the remaining for preventive maintenance works. A two-step optimization will be applied to model: in the first step, the minimum budget for satisfying all constraints will be estimated. This step could give a long-term view to decision makers. In the second step, a higher budget (subject to more available funds) could exceed the outcome of the first step optimization and will be applied to find an optimum solution and maximum performance. However, in this study, an innovative approach is proposed to classical one for the second step with the ability of the model to select side by side segments, saving funds, and reducing incoordination issues. The performance of a road segment ($P_{s,t}$) could be estimated based on any performance index such as international roughness index (*IRI*). The first step optimization model is shown in Equations 1 to 4 and Equations 5 to 6 present classical formulations for the second step optimization.

Step I:

$$[1]\ MIN(C_t) = \sum_{s=1}^{S} C_{s,t} X_{s,t} l_s$$

Subject to

$$[2]\ P_s < P_{s,t} \quad and \quad P_o < P_t$$

$$[3]\ P_t = \frac{\sum_{s=1}^{S}(l_s \times P_{s,t})}{\sum_{s}^{S} l_s}$$

Where the following time dynamic link applies.

$$[4]\ P_{s,t} = X_{s,t}\left(P_{s,t-1} + Pi_{s,t}\right) + \left(1 - X_{s,t}\right)\left(P_{s,t-1} - Pd_{s,t}\right)$$

Step II (Classical model):

$$[5]\ MAX(P_t) = \sum_{s=1}^{S}(l_s \times P_{s,t})$$

Subject to:

$$[6]\ 0 < \sum_{s=1}^{S} C_{s,t} X_{s,t} l_s \leq B_t \qquad B_t > C_t$$

Where:

[7] $X_{s,t} = \begin{cases} 1 \ \ if\ action\ is\ taken\ on\ segment\ s, in\ the\ year\ t \\ 0 \ \ if\ no\ action\ taken\ on\ segment\ s, in\ the\ year\ t \end{cases}$

P_t = Overall performance in the network or road on year "t'

$P_{s,t}$ = Performance of segment "s" on year "t" on a 0 to 100 scale

C_t = Minimum budget ($) as given by Equation 1 on year "t"

$C_{s,t}$ = Unitary cost ($) of rehabilitation action of segment "s" on year "t"

$Pi_{s,t}$ =Improvement portion from the year (t-1) to year "t" for segment "s"

$Pd_{s,t}$ =Dropped portion of performance from the year (t-1) to year "t" for non-selected segment "s"

P_s=Minimum acceptable performance for one segment respecting safety threshold

P_o=Minimum acceptable performance overall a network or road

l_s= Segment "s" length

In case of using *IRI*, due to nature of index, maximum acceptable levels as thresholds will be used and the objective would be minimizing overall *IRI*.

For this study, Equations 5 and 6 could be customized to reduce the cost for those segments which are selected sequentially in each time period plan. As it is mentioned in the cost estimating manual for projects, published by Washington State Department of Transportation (WSDOT) (2015) mobilization and demobilization cost is adjustable contractor's preconstruction expenses in transportation activities which could be changed from 5 to 12% of the construction cost depending on the contract value. However, working in adjacent segments drops the construction costs as well as accelerates activities which directly decrease the overall cost. Therefore, the contractor will gain even more than the suggested rates for the mobilization percentage. Typical decision rules are implemented in developed optimization model as follows:

If two sequential segments are assigned the same treatment action in the one-time period, 10% reduction of treatment costs in the smaller segment will be applied. Meanwhile, for different selected actions in two side by side segments, 5% drop could be used which is applied to less total price treatment. The above formulation also addresses coordination and user costs by reducing traffic flow disruptions and improving safety; however, future studies could add this factor (delay caused by road maintenance projects) in the decision-making process.

2 CASE STUDY

Highway 417 west (King's Highways) in Canada is selected as a case study. This freeway connects Montreal City in Quebec to Ottawa in Ontario. Around 180 km from Quebec border to the end of the highway in Ontario is analyzed in this study. Provincial Traffic Volumes (2016) indicates that traffic load in this highway could be categorized in three levels: low, medium and high based on 22000, 80000, 160000 annual average daily traffic volume (AADT), respectively. The highway is mostly including four lanes with low AADT; however, partially has six and eight lanes in medium and high traffic portions, respectively.

Deterioration trends for each traffic load group are developed based on Paterson and Attoh-Okine (1992) model (Equation 8) where IRI is predicted through equivalent single-axle loads (*ESAL*), thornthwaite moisture index (*m*), structural number (*SNC*) and initial as-built quality (IRI_0). The almost similar environmental condition is observed in this case and *SNC* is calculated based on AASHTO (1993). As-built quality (IRI_0) is set to 0.8 and the coefficient α is set to 265 (Zareie et al. 2016).

$$[8]\ IRI_t = e^{mt}[IRI_0 + \alpha(SNC)^{-5} \times ESAL_t]$$

Treatment action windows and pavement lifespans are developed based on pavement design and rehabilitation guidelines (Government of New Brunswick 2018; Ontario Ministry of Transportation 2018) in Table 1. Also, British Columbia ministry of transportation and infrastructure (2013) guideline for rehabilitation costs is used for developing this table; however, the costs are presented in $US. Maximum twice preventive maintenance is allowed to be applied to each segment to avoid the inefficiency of treatments. Based on these guidelines, overall *IRI* should be set on less than 1.5 m/km and 2.7 m/km is defined as the poor threshold for each segment corresponding to 15-year lifespan. Pavement condition observations for 2014 are collected from Ministry of Transportation (2018) and since the shortest segment in this report is 3.64 km, the highway is divided into 45 segments, each four kilometers long. Planning intervals could be set respecting road current condition, segments length, agency policy, deterioration rates, and seasonal construction duration in each year. In this study, since the current overall condition is good, the model is run for each 4-year time period to give flexibility for clustering. Also, results could be comparable with government rehabilitation plan for the same road.

Table 1: Treatment and Operational Windows for pavement

Treatment	Drop in IRI	Cost ($US/lane.km)	Lower IRI (m/km)	Upper IRI (m/km)
Do nothing	0.00	0	0.00	1.10
Preventive maintenance	0.54	4,000	1.11	1.56
Minor rehabilitation	0.90	40,000	1.57	2.08
Major rehabilitation	1.40	100,000	2.09	2.70
Reconstruction	Brand New	220,000	2.71	-

The model is run for this case study and the minimum budget was derived for each time period (Figure 2). The minimum required budget has been increased particularly after 20 years. Two groups of segments are observed in this highway, and the first group has a poor condition (more than *IRI* 2 m/km) and approaching the end of its life cycle. In the second group, several segments with *IRI* around 1 m/km are observed and this situation improved the overall *IRI*, which is 1.46 m/km and less than acceptable level. Therefore, the model in the first step concentrates more on critical segments (first group) and ignore the rests. Thus, preventive actions are ignored in this step and additional budget is needed for the second step of the optimization.

To test the model, the results are compared with the Ontario ministry of the transportation plan for 2014-2018 and 2015-2019 (Ontario Ministry of Transportation 2018). Seven segments were selected by the model for major rehabilitation while the Ontario ministry of transportation rehabilitation plan shows that 17 segments were picked for resurfacing as a major rehabilitation action in the 5-year plan in both directions of west and east. Analyzing the results indicates that same approach is applied by the government for east direction and very similar segments were selected for rehabilitation in the first plan (2014-2018). The model also assigned preventive maintenance to only 4 segments to respect the overall performance threshold (*IRI*<=1.5 m/km); however, as it can be seen in Figure 2, it is not a proper long-term approach and brings more future costs as a result of ignoring enough preventive actions and concentrating only on critical segments. In order to reduce this future cost, more than minimum required budget should be assigned to this highway.

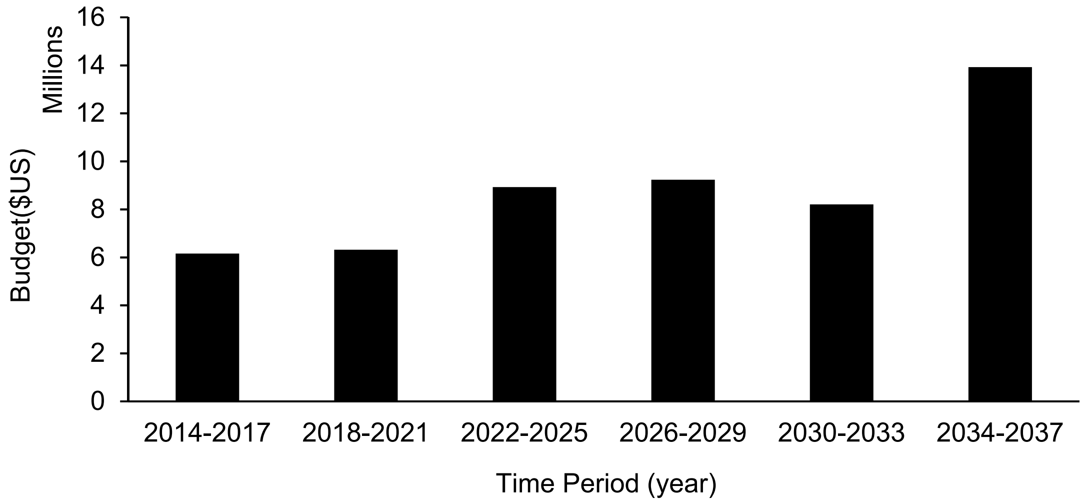

Figure 2: Minimum budget for respecting thresholds

Respecting the results of the first step, the budget is increased to 6,500,000 $US for each 4-year time period and is applied to both the classical and the developed model in this study to minimize the overall condition while respecting thresholds of condition and budget. Figure 3 presents overall *IRI* in both approaches and a slightly better condition is achieved by proposed approach in this study. Average IRI is 1.12 and 1.14 for the new and classical model, respectively.

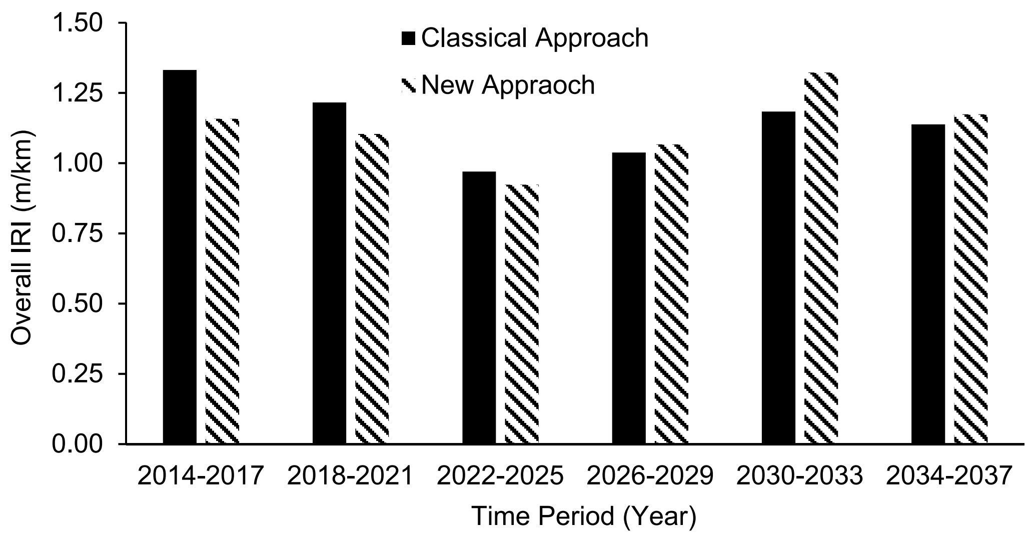

Figure 3: Overall IRI (m/km) in classical and new model

Figure 4 presents the total expenditures in each approach. The first interesting point in these figures is the very high efficiency of preventive maintenance actions. By adding less than $US 500,000 to the minimum budget at the beginning, the agency could reduce the total cost significantly while dropping required budget for the 2026-2033 periods with less than $US 500,000 due to an acceptable level of performance (IRI<=1.5 m/km) in all segments. The novel model even could gain more and only need the assigned budget ($US 6,500,000) for two cycles of 2014-2017 and 2018-2021. Comparing Figures 3 and 4 indicates that new formulation could save $US 5 million, while similar performance is achieved.

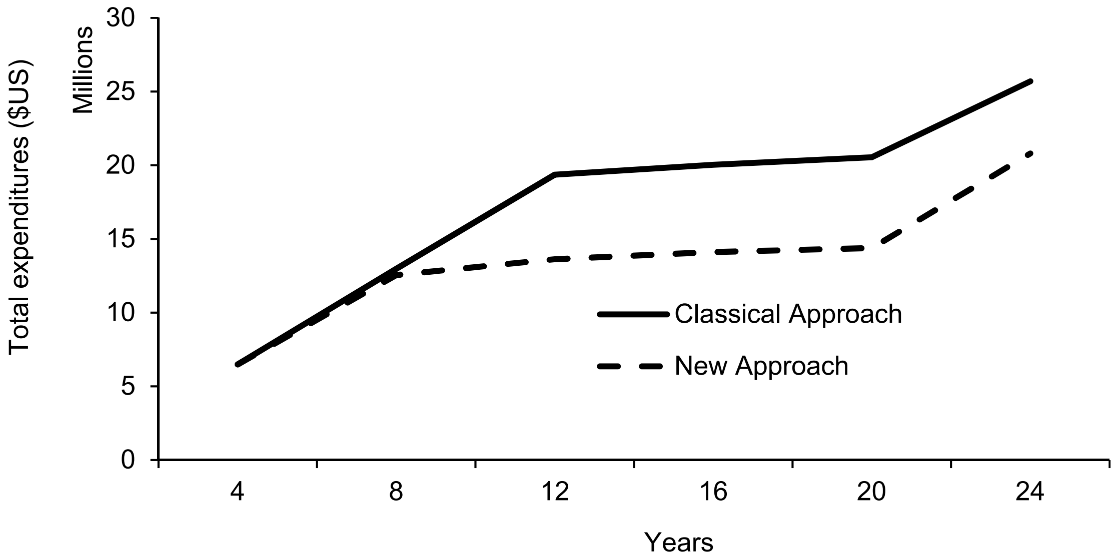

Figure 4: Total expenditure in the classical and new formulated model

3 CONCLUSION

The classical approach for providing intervention in RAM involves two distinct steps of planning and implementation which result in wasting money and time. This paper suggested a framework to establish a formalized asset management procedure with a focus on the principles of lean construction. The model focuses on eliminating wastes including mobilization and demobilization costs in the construction phase to enhance value in road management process. To test the model, the results were compared with the Ontario ministry of the transportation plan for 2014-2018 and 2015-2019 (Ontario Ministry of Transportation 2018) for Highway 417 in Ontario, Canada. Long-term analysis of this freeway showed that an approximate budget of $US 25,000,000 for 24 years is required to keep this freeway at an acceptable level of service. However, the developed formulation for this case study could drop the approximate budget by about 20% and still achieve a similar level of service.

References

AASHTO. (1993). *AASHTO Guide for Design of Pavement Structures, 1993* (Vol. 1). AASHTO.

Amador, Luis, and Sherry Magnuson. "Adjacency Modeling for Coordination of Investments in Infrastructure Asset Management: Case Study of Kindersley, Saskatchewan, Canada." *Transportation Research Record: Journal of the Transportation Research Board* 2246 (2011): 8-15.

British Columbia ministry of transportation and infrastructure. (2013). Construction and Rehabilitation Cost Guide. https://www2.gov.bc.ca.

Faghih-Imani, Ahmadreza, and Luis Amador-Jimenez. From Strategic Optimization to Tactical Plans: Coordinating Treatments of Road Infrastructure. No. 13-0632. 2013.

Fewings, P. (2013). *Construction project management: an integrated approach.* Routledge, Ney York.

Galenko, Alexander, Eric Perrone, and Tonya Scheingberg. "Project Coordination Model." *Procedia Computer Science* 52 (2015): 83-89.

Government of New Brunswick (2018), Capital Maintenance of Highways, chapter 5, http://www2.gnb.ca/content/gnb/en.html

Osman, Hesham. "Coordination of urban infrastructure reconstruction projects." *Structure and Infrastructure Engineering* 12, no. 1 (2016): 108-121.

Lee, Eul-Bum, C. William Ibbs, and David Thomas. "Minimizing total cost for urban freeway reconstruction with integrated construction/traffic analysis." *Journal of infrastructure systems* 11, no. 4 (2005): 250-257.

Morgado, João, and José Neves. "Work zone planning in pavement rehabilitation: Integrating cost, duration, and user effects." *Journal of Construction Engineering and Management* 140, no. 11 (2014): 04014050.

Moreira, André V., Tien F. Fwa, Joel RM Oliveira, and Lino Costa. "Coordination of User and Agency Costs Using Two-Level Approach for Pavement Management Optimization." *Transportation Research Record: Journal of the Transportation Research Board* 2639 (2017): 110-118.

Oh, Jun-Seok, Hyunmyung Kim, and Dongjoo Park. "Bi-objective network optimization for spatial and temporal coordination of multiple highway construction projects." *KSCE Journal of Civil Engineering* 15, no. 8 (2011): 1449-1455.

Ontario Ministry of Transportation (2018), Pavement condition for provincial highways, https://www.ontario.ca/data/pavement-condition-provincial-highways

Ontario Ministry of Transportation (2018), Pavement design and rehabilitation manual, second edition, www.bv.transports.gouv.qc.ca/mono/1165561.pdf

Ontario Ministry of Transportation (2018), Southern Highways Program (2014-2018), http://www.mto.gov.on.ca

Ontario Ministry of Transportation (2018), Southern Highways Program (2015-2019), http://www.mto.gov.on.ca

Santos, Bertha, Luis Picado-Santos, and Victor Cavaleiro. "Road User Costs in Pavement Management Systems: Methodologies and Costs." In *Proceedings of the Fourth International Conference on Maintenance and Rehabilitation of Pavements and Technological Control*. 2005.

Theiss, LuAnn, Gerald Ullman, and Amy Moinet. *Guide to Project Coordination for Minimizing Work Zone Mobility Impacts*. No. FHWA-HOP-16-013. 2016

Washington State Department of Transportation (WSDOT), 2015, Cost Estimating Manual for Projects, 3034.03, ttps://www.wsdot.wa.gov

Womack, J. P., and Jones, D. T. (2010). *Lean thinking: banish waste and create wealth in your corporation.* Free Press, New York.

Yang, Jidong. "Nested Markov Decision Framework for Coordinating Pavement Improvement with Capacity

Expansion." *Journal of Transportation Engineering* 138, no. 4 (2012): 387-394.

Zareie, Alireza, Md Shohel Reza Amin, and Luis E. Amador-Jiménez. "Thornthwaite moisture index modeling to estimate the implication of climate change on pavement deterioration." *Journal of Transportation Engineering* 142, no. 4 (2016): 04016007.