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Critical Infrastructure Renewal: A Framework for Fuzzy Logic Based Risk Assessment and Microscopic Traffic Simulation Modelling

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Abstract

This paper presents a comprehensive framework for risk assessment and micro simulation modelling to assess traffic impacts during re-decking of a major suspension bridge identified as Critical Infrastructure (CI) in Halifax, Canada. The bridge is being replaced while maintaining traffic during day time. As re-decking is relatively a rare and unknown construction event for a Cable Bridge, unexpected risk event and uncertainty would be associated with complex engineering manoeuvring during the re-decking of the bridge. Therefore, this study proposes a fuzzy logic approach to estimate the construction related bridge opening delay, and subsequently develops a micro simulation-based traffic network model to assess the traffic impacts on transport network. Weather data, traffic volume and signal data obtained from multiple data sources have been used during the risk assessment and micro simulation modelling. The results suggest that the likelihood of bridge opening delay could range from 18%-30% for an hour period to 40% for 3 hour period depending on the level of consequence on any day in December. The average potential delay is obtained as 22 minutes, 1.5 hours, and 2.6 hours for low consequence, medium consequence, and high consequence respectively. Based on the delay analysis, this study evaluates three alternative bridge opening delay scenarios. It is observed that the increment in number of operating vehicles becomes steady at 30% suggesting the network has reached its capacity. The results also reveals that any delay over 2 hours in bridge opening would add a slight change to the impacts on the network. This study will help policy-makers to develop risk mitigation plans and contingencies to ensure better management of traffic during 18 months long re-decking of this critical infrastructure.

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Keywords: re-decking; fuzzy logic; delay probability, micro simulation; traffic impacts.

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1. Introduction

Risk is inherent in large construction projects and refers to the potential complications in achieving the project goals. Risk has greatly plagued the construction industries which necessitates the risk assessment for the large scale construction projects. Especially, risk assessment is critical for new construction or renewal of 'Critical Infrastructure (CI)', such as bridges as they are the vital links for a transport network. Gradually increasing complexity in road construction and constant exposure to environmental conditions increase the vulnerability of large Critical Infrastructure construction projects to the unexpected hazardous events. Literature offers a plenty of evidence of the schedule slippage and thereby failures to attain the objectives of construction projects. Many factors such as weather, labor skill, and incidents are liable for construction delays and cost overruns of the projects (Baldwin et al., 1984; Ayyub and Halder, 1984; Smith and Hancher, 1989). Among many, the most weather- susceptible road construction activities might include earthwork, road paving, and structural work, including bridge re-decking and activities involving the use of heavy crane machinery (Apipattanavis et al., 2010). These risk factors and events have made the road construction delay a likely circumstance, often having significant impacts on project duration and traffic flows on surrounding road network. Although the delay of road construction projects cannot be avoided, the associated impacts on road network can be assessed and mitigated prior to commencing construction. Recently, Halifax Harbour Bridge (HHB) Commission has begun a re-decking project known as the "Big Lift" (2015-2017) in order to replace the suspended spans of the Macdonald Bridge, a 1.3 km long Critical Infrastructure (CI) in Halifax, Canada. After the Lions' Gate Bridge re-decking in Vancouver (2000-2001), this is the second time in history a suspension bridge is being replaced while maintaining traffic during day-time. The project will last for almost 18 months. The associated risk and potential impacts could be significant as up to 48,000 vehicles, 700 cyclists, and 750 pedestrians cross the bridge every day, yet the consequences of disruption to the Macdonald Bridge have never been studied (Quigley, 2015).

Therefore, this paper presents a fuzzy logic approach to estimate the construction-related bridge opening delay, and develops a micro simulation model to assess the traffic impacts due to unexpected bridge opening delay during the "Big Lift" project. The re-decking has been started in October, 2015. Construction commences from 7:00 pm, with the bridge becoming operational again at 5:30 am the following morning. The main objectives of this study is (i) to develop a framework to estimate the construction related bridge opening delay in the morning, and (ii) to assess the traffic impacts due to bridge opening delay utilizing a micro simulation model. The delay risk analysis feeds the simulation process with the delay information required to test the possible case scenarios in AM peak period. The scenarios include (i) Base case scenario (no delayed opening) (ii) 1 hour delay (iii) 2 hour delay, and (iv) 3 hour delay in bridge opening to traffic in the morning. The impacts are evaluated based on specific Measures of Effectiveness (MOEs) such as average queue length, average travel time, average delay, average speed, and traffic flow indicators.

2. Literature review

Construction is susceptible to various risks such as construction phase related risk, weather, political and contract provision, finance, environmental, and design related risks. Schedule slippage is inherently embedded into construction projects as a result of potentially unforeseen events. A survey, conducted for forty US construction managers and owners revealed that at the beginning of the project, only 35% of the assessed projects had been found to have a low uncertainty. This means that the remaining 65% of the projects had a medium to very high uncertainty (Laufer et al., 1992). Literature review suggests that sometimes teams of experienced engineers and practitioners are unable to anticipate this uncertainty. Therefore, risk assessment plays a vital role in construction engineering. Many studies have investigated project risk, activity scheduling, and construction delays, risk factors and risk management methods. For example, a study identified a couple of factors such as heavy rain and delay in labor payment are the main causes responsible for the cost escalation and schedule delay in road construction (Kaliba et al., 2009). However, a majority of these studies have focused on small-scale construction and routine roadway management. As indicated earlier, risk assessment is critical for CI construction projects; several researchers have conducted risk assessment studies for critical infrastructure development projects, including bridges and nuclear power plants (Nieto Morote and