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Acquiring insights into infrastructure repair policy using discrete choice models

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ABSTRACT

Infrastructure agencies routinely make maintenance, rehabilitation, and reconstruction (MRR) decisions to keep their assets in state of good repair or to extend their service lives. They use one of three general mechanisms to make such decisions: expert opinion, continuation of historical practices, or explicit optimization using costs and benefits data for alternative MRR actions. In using any of these decision mechanisms, the agency is guided by decision factors (i.e., the attributes of the infrastructure, the operating environment, and the action in question). With regard to the historical-practice mechanism where the agency's MRR policy is governed by past MRR decisions, there typically exists ample data on past decisions as well as the decision factors that existed at the time of the decision and hypothetically influenced the decision. Agencies that still use this decision mechanism continue to grapple with several issues, which include the feasibility of modeling the agency's past decisions as a function of the decision factors prevailing at the time of the decision; and the influence of the decision factors on the decision outcome (MRR choice) and the temporal stability of such influences. This paper demonstrates a proposed framework to address these questions using data associated with in-service bridge decks at a highway agency in Midwestern USA. This paper also discusses the insights gained about bridge infrastructure repair policy by assessing the sensitivity of past decisions to the decision factors. The paper also demonstrates how the framework can be used to develop MRR-choice probability distributions to guide future MRR decisions and then to estimate the funding needs for future bridge deck actions. Agencies can use the methodology presented in this paper for work decisions, training of new personnel, and long-term work planning and budgeting.

1. Introduction

In most countries, the transportation infrastructure constitutes the most valuable government-owned asset and typically requires annual investments that often exceed several billions of dollars (FHWA and AASHTO, 1996; OECD, 2000; TAC, 2000; INGENIUM, 2011; CBO, 2017; Moloney et al., 2017). These investments generally serve to preserve (reconstruct, rehabilitate, and maintain) the existing infrastructure. The United States, for example, has four million miles of public roads and over 550,000 bridges which are collectively worth over one trillion dollars in value, and spends approximately 50 billion dollars annually maintaining this infrastructure (FHWA, 2012a). Considering the nation's inventory of 8.6 million lane-miles and three trillion vehicle miles of travel (FHWA, 2012b), this expenditure translates into a loaded annual average of $5800/lane-mile or 1.7 cents per vehicle mile traveled

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Table 1
Infrastructure repair decision mechanisms in practice and in the literature.

Expert opinion	Historical practice	Explicit optimization
Hicks et al. (1997), Myamoto et al. (2001), Saito and Sinha (1989), Lamptey et al. (2005)	Madanat and Mishalani (1998), Myamoto et al. (2001), Lamptey et al. (2005)	Sinha et al. (1989), Abaza (2002), Sun et al. (2005), Pasupathy et al. (2007), Durango-Cohen and Madanat (2008),Lamptey et al. (2008), Mbwana and Turnquist (1996), Irfan et al. (2009),Sinha et al. (2009), Fan and Song (2009), Adey and Hajdin (2011), Walbridge et al. (2012), Le Thanh et al. (2016), Adey (2017)

(VMT). This overall expenditure is expected to increase further due to the ever-increasing infrastructure inventory, higher expectations of infrastructure levels of service, infrastructure aging, increased frequency and intensity of severe weather, and increasing traffic loads.

The massive size of the transportation infrastructure inventory, the vital importance of transportation infrastructure to economic development, and the large amount of investments in their repair and renewal continue to inspire the search for improved policies for the management of such infrastructure (Adey et al., 2017; Taggart et al., 2017). Even a small marginal savings that can be earned if cost-effective practices are followed, translates into several billions of dollars. The quest to enhance infrastructure perseveration policies and practices is manifest in the literature that are associated with each phase of infrastructure development: design, construction delivery and procurement, operations, maintenance, and end-of-life. In the literature, there is unanimous agreement on the need for more informed and reliable repair options decision-making for infrastructure (Weykamp et al., 2010). To address the growing MRR funding needs for their infrastructure, agencies continue to seek solutions in three key areas: technological innovation (materials and designs that yield durable infrastructure with lower life cycle costs); enhanced monitoring of infrastructure usage and condition; and strategic decisions and policies for MRR. With regard to the third initiative, agencies develop strategic MRR policies through at least one of three mechanisms, which are discussed in the next section.

1.1. Repair decision mechanisms

Agencies carry out MRR actions to keep their assets in good repair or to extend their service lives. In this paper, the term “repair” is used to represent MRR in a general sense. In making repair decisions, infrastructure agencies typically rely on one of three general resources: expert opinion, historical practice, and data-driven cost and benefit analysis such as optimization (Table 1). These resources are referred to as “decision mechanisms.”

The use of expert opinion to choose the most appropriate repair option is common where the infrastructure agency lacks not only documented records of their past practices but also methodologies for data-driven cost and benefit analysis such as optimization to implement these methodologies. Historical practice, on the other hand, implies that the current agency repair policy is simply based on the way it made repair decisions in the past. As a side note, this is consistent with what is termed in the economic literature as “revealed preference” (in contrast to “stated preference” which is the case for policy based on expert opinion). Agencies typically use this mechanism for making repair decisions where they lack experts (often due to cohort retirement of experienced engineers or rapid turnover of such personnel due to market forces) or lack data or methodologies for explicit cost and benefit based optimization. In the research literature, there have been relatively few efforts to use past agency decisions model the choice of repair decisions/actions. Mohamed et al. (1997) developed a binary model (whether or not maintenance was carried out at a given pavement section) as part of a mixed logit framework and determined that colder regions, thinner pavements, higher traffic load and poorer condition pavements generally have higher probabilities of receiving maintenance. Madanat and Mishalani (1998) used a multinomial logit (MNL) model to predict probabilities of do-nothing, routine maintenance, and rehabilitation for highway pavements. Labi and Sinha (2003) advocated for lagged maintenance occurrence models whose response variable could be (a) a 0–1 binary value in a maintenance decision model, or (b) a continuous value (amount of money spent on maintenance). Durango-Cohen (2004) assumed that the infrastructure facility is managed under a periodic review policy and developed repair decision models that do not account for the infrastructure condition.

Agencies are generally aware of the limitations inherent in the mechanisms involving expert opinion or historical practice. Thus, they desire to select repair options based on a mechanism involving data-driven analysis of the costs and benefits of each candidate repair option (Park and Robert, 2012), and a significant number of contemporary academic literature on the subject is dominated by the use of this mechanism for decision-making (Sinha et al., 1989; Frangopol and Estes, 1999; Abaza, 2002; Lamptey et al., 2008). Unfortunately, it is not always easy to translate such research to practice because agencies either lack mature and fully-functioning automated decision support systems (DSS) for explicitly making choices among repair options or are licensees of these packages, but do not yet use them effectively due to barriers that include lack of data, lack of expertise in using the DSS package, or institutional inertia. Until agencies reach a mature stage of asset management practice, they will continue to use expert opinion and historical practice as the primary mechanisms for choosing between repair alternatives. Even at agencies that use automated asset management systems, such systems cover only the major asset types (pavements and bridges); for ancillary assets, expert opinion and historical practices are still being used to make repair decisions (Akofio-Sowah et al., 2013).

In reality, there could be overlaps between the three decision mechanisms with respect to the manner of their application in practice. For example, in certain cases, the repair options elicited through expert opinion are modified, directly or indirectly, by the historical practices of the agency. In other words, the prescriptions offered by the experts may be influenced by which repair option