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Optimal funding allocation strategies for safety improvements on urban intersections

Sabyasachee Mishra [a,d,*], Mihalis M. Golias [a,d], Sushant Sharma [b], Stephen D. Boyles [c]

[a] Department of Civil and Environmental Engineering, University of Memphis, 3815 Central Avenue, Memphis, TN 38152, United States
[b] Texas A&M Transportation Institute, 1100 N.W. Loop 410, Suite 400, San Antonio, TX 7821, United States
[c] Department of Civil, Architectural and Environmental Engineering, University of Texas at Austin, 301 E. Dean Keeton St. Stop C1761, Austin, TX 78712, United States
[d] Intermodal Freight Transportation Institute, University of Memphis, 302 Engineering Sc. Bldg., Memphis, TN 38152, United States

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ABSTRACT

Urban intersections crashes cause significant economic loss. The safety management process undertaken by most states in the United States is referred to as Highway Safety Improvement Program and consists of three standardized steps: (i) identification of critical crash locations, (ii) development of countermeasures, and (iii) resource allocation among identified crash locations. Often these three steps are undertaken independently, with limited detail of each step at the state planning agencies. The literature review underlines the importance of the third step, and the lack of sophisticated tools available to state planning agencies for leveraging information obtained from the first two steps. Further, non-strategic approaches and unavailability of methods for evaluating policies may lead to sub-optimal funding allocation. This paper overcomes these limitations and proposes multiple optimal resource allocation strategies for improvements at urban intersections that maximize safety benefits, under budget and policy constraints. Proposed policy measures based on benefits maximization (economic competitiveness), equitable allocation (equity), and relaxation of mutually exclusiveness (multiple alternatives at one location) produce significantly different alternative and fund allocation. The proposed models are applied to selected intersections in four counties of southeast Michigan. Results reinforce the applicability of the strategies/policies and tools developed in this paper for safety project funding allocation on critical urban intersections.

1. Introduction

Moving Ahead for Progress in the 21st Century (MAP-21) is a milestone that envisions research and application focus areas for surface transportation in the United States (USDOT, 2012). MAP-21 sanctioned continuation of the legacy Highway Safety Improvement Program (HSIP) as a core Federal-aid program. HSIP envisions significant reduction in traffic fatalities and serious injuries on the highway system. Under HSIP, State Departments of Transportation, along with the US Department of Transportation (USDOT), spend billions of dollars annually for safety improvements at road infrastructure. In addition, the United Nations has named the present decade the "Decade of Action for Road Safety". The target of this

* Corresponding author at: Department of Civil and Environmental Engineering, University of Memphis, 3815 Central Avenue, Memphis, TN 38152, United States. Tel.: +1 901 678 5043; fax: +1 901 678 3026.
E-mail addresses: smishra3@umd.edu (S. Mishra), mgkolias@memphis.edu (M.M. Golias), s-sharma@tamu.edu (S. Sharma), sboyles@mail.utexas.edu (S.D. Boyles).

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campaign is to reduce the number of fatalities by 50%. In the highway safety arena, both national and worldwide goals include reducing the number of fatalities and serious injuries (UN, 2014).

The safety management process undertaken by most states is often referred to as the Highway Safety Improvement Program (HSIP), which consists of three steps: (1) selection of candidate locations where safety improvements are warranted; (2) development of countermeasures for potential crash reduction; and (3) allocation of resources among candidate locations in conformance with budgetary and other constraints. State planning agencies often consider these three steps as independent and sequential. Resource allocation (third step) is the most critical phase, and any limitations of the analysis tools used, leads to suboptimal funding allocation with reduced safety benefits and long-term capital loss.

Two critical components of a safety improvement program are crash prediction and funding allocation for preventative measures. The crash prediction component models the trajectory of future crashes. The traditional approach in crash prediction ignores randomness and assumes a deterministic growth factor for the number of crashes. This assumption intrinsically may lead to suboptimal allocation of highway safety improvements, and incorporating the random nature of crashes is critical to achieve robust safety alternative allocation. The second component of a safety improvement program is funding allocation. In this component, funds are distributed for implementing safety alternatives at pre-identified hazardous locations. Current state-level fund allocation strategies suffer from short-term planning, and inefficient/sub-optimal resource allocation due to the absence of optimization-based tools. Further, there is lack of: (i) concrete policies that maximize long-term safety benefits and (ii) policy tools to evaluate implementation and safety benefits. In this paper we focus on the second component of a safety improvement program and propose mathematical models that address the following research question:

"How to optimally allocate funding within a state for implementation of safety measures at locations with existing crash history within budget, planning period and strategic/policy constraints?"

To answer this question we propose an approach to optimize safety benefits in a given region by maximizing the dollar value from crash reduction at intersections over a multi-year planning horizon. The primary contributions of the paper are as follows:

- A resource allocation model is developed that assigns safety alternatives to locations based on crash types so the overall crash reduction benefits are maximized subject to budget and policy constraints.
- Three policy options based on federal and state vision plans are proposed and mathematically modeled to represent realistic issues encountered by the planning agencies during fund allocation:
  - The first policy maximizes total economic and safety benefits and is based on federal policy level goal of economic competiveness.
  - The second policy measure is equity consideration in the benefits and allocation of safety measures among counties.
  - The third policy relaxes the mutually-exclusive nature of improvements and allows locations to receive more than one improvement in a given year if doing so maximizes benefits while satisfying specified constraints.

The remainder of the paper is organized as follows: the next section presents the literature review specific to resource allocation models, followed by the methodology and model formulation. The data set used for demonstration and model application is discussed in the later sections. Finally, the models and results are summarized and recommendations for future research are outlined.

2. Literature review

The literature review is organized into three sections: (1) highway safety resource allocation, (2) analytical methods of highway safety resource allocation and (3) equity-based policy measures in transportation planning. The review presented is by no means comprehensive; rather it captures a representative cross-section of studies conducted on this subject in past two decades.

2.1. Highway safety resource allocation

Resource allocation and prioritizing highway safety projects is identified as an important element in transportation planning (AASHTO, 2010). Depending on the severity of crashes, investment in capital, operation and maintenance (O&M) costs may vary significantly. The literature contains a number of studies devoted to identifying hazardous locations. However, only a fraction of locations initially identified as hazardous are actually selected for implementation of safety projects because of funding limitations. These are discussed extensively in the literature (Cook et al., 2001; Hauer, 1996; Hossain and Muromachi, 2012; Lambert et al., 2003; Lyon et al., 2007; Tarko and Kanodia, 2004). The key question remains with knowledge of pre-determined hazardous crash locations and available possible countermeasure, how to prioritize the fund allocation process considering varying real life constraints.

2.2. Analytical approaches for highway safety resource allocation

The topic of resource allocation (using optimization techniques) spans diverse areas such as operations research, manufacturing, management, finance, and transportation. Optimization usually involves maximization or minimization of an