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Shared automobile, bicycle, and pedestrian facilities: Toward a multi-objective approach to selecting maintenance actions

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1.Introduction

Over the past three decades, the importance of providing an efficient multi-modal transportation system has been recognized in terms of the contributions to quality of life, livability, healthy living, and sustainability. In the United States, programs, and initiatives, such as Smart Growth, Complete Streets, Context Sensitive Design, Safe Routes to School, Recreational Trails Program, Transportation Enhancements and Active Living, have contributed to growing awareness of the value of non-motorized modes of transportation and transit. Many are intended to encourage transit usage, and non-motorized modes of travel while accommodating auto travel. Legislation, including The Americans with Disabilities Act (ADA), The Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), The Safe and Complete Streets Act, The Safe Routes to School Act. The Active Communities Transportation (ACT) Act, and The Livable Communities Act, has also emphasized these modes (de Zeeuw & Flusche, 2011).

Common to all these programs and initiatives is the fact that frequently the different modes share the right of way, such as complete streets, and in some cases specific facilities, such as dedicated bike and pedestrian paths and bike lanes on urban streets. Guidelines are readily available for the design of such facilities, but little attention has been paid to maintenance and rehabilitation decisions and supporting multi-modal travel during maintenance and reconstruction. Although the Manual of Uniform Traffic Control Devices (MUTCD) and the AASHTO design guide indicate that motorists, pedestrians (including persons with disabilities) and bicyclists must be accommodated through a temporary traffic control zone (Huber, et al., 2013), experience suggests otherwise. Specifically, projects such as roadway repaving and reconstruction generally pay little attention to the disruptions to pedestrians and bicyclists beyond putting up a sign indicating the pedestrian or bicycle route is closed, maintenance of pedestrian and bicycle facilities appears, from the user perspective, to be haphazard and unplanned, and maintenance activities seem uncoordinated across modes.

Given the different maintenance needs for different types of facilities, this research explores the issues involved in accounting for the disruption to all modes and the strategies for maintenance decision-making and scheduling that recognize all users. The objective is to develop strategies for selecting maintenance actions for bike, pedestrian, and auto facilities that share the right of way accounting for disruptions whose impacts cascade across modes. The proposed strategies build on principles of asset management and work with the construct of the transportation system as a sociotechnical system. Given that these decisions are commonly the responsibility of local governments with few resources, a secondary objective is to develop guidelines to help local governments develop strategies without an onerous data collection and modeling effort.

This extended abstract motivates the need for this research and presents a preliminary, qualitative formulation. The presentation is organized into six additional sections. The following section reviews what we know from the literature. This is followed by a section on performance measures and then general concepts used in the formulation of the problem. A discussion of the data required and a realistic network to explore options is presented. Finally, the anticipated challenges and expected results are presented.

2. What we know from the literature

This work builds on the literature from eight different areas: socio-technical systems, current practices for facility design of multimodal facilities, asset management, condition assessment of bicycle and pedestrian facilities, walkability and bikeability scores, levels of service, potential maintenance actions and costs, and multi-criteria analysis for bicycle and pedestrian facilities. This section concludes with a summary of the gaps in the literature.

Infrastructure systems in general and transportation systems are characterized as socio-technical systems (Little, 2004; Ottens, et al., 2006), a system in which end users play an active role in determining how well technical components are able to serve them (Vodopivec & Miller-Hooks, 2019). While much of the relevant literature on socio-technical infrastructure systems focuses on resilience, infrastructure interdependencies, and new technology, the construct also applies to systems, such as the roadway, bicycle, and pedestrian systems that we are concerned with in this paper, because technical decisions should reflect user experiences, perceptions, and behaviors. For example, level of service for bicyclists and pedestrians varies by population group, such as commuters versus recreational users, or for visually or mobility impaired pedestrians.

The design of multi-modal facilities in the shared right-of-way requires consideration of efficiency, safety, accessibility, mobility, and sustainability. There is a growing body of literature on complete streets and active transportation design and implementation that helps to identify relevant objectives and constraints.

Similarly, the maintenance of roadways has received considerable attention over the last four decades building on work on pavement management and evolving into the more general work on asset management that recognizes the value of a data driven decision process that includes both goals and resources constraints. Literature on roadway paving, road reconstruction, and asset management includes what decisions to make and when, life cycle cost analysis, deterioration models, strategies for making optimal decisions, and scheduling.

Work on condition assessment of sidewalks and bicycle facilities recognizes the need for both inventory and condition data. However, the level of detail varies from application to application. Specific data on tripping hazards has been connected to safety data, thresholds for maximum surface discontinuities and slopes are part of the ADA guidelines (Huber, et al., 2013), and an overall sidewalk condition is a contributor to the level of service (Transportation Research Board, 2016). Vavrova and Chang (2019) use a bikeway pavement condition index (BPCI) based on a score of 0 to 100 where below 65 is considered poor condition, 84 to 65 fair condition and above 84 is good condition. The BPCI is based on a visual assessment of potholes, cracking, debris, gravel and draining grates. Vavrova and Chang also use the remaining life of pavement marking as a condition measure, where brand new markings have a remaining life of four year and markings needing maintenance have no remaining life.

Other useful concepts are walkability and bikeability, and level of service. Walkability and bikeability indices indicate the opportunities for pedestrian and bicycle-oriented activity in an area. Level of service indicates how well facilities are performing. These are composite measures that vary in scale and method, but all attempt to capture characteristics of the environment, physical conditions, and capacity. The walkability and bikeability indices capture desirability, and level of service captures the amount and nature of demand.

A literature review focusing on the maintenance of bicycle and pedestrian facilities provides an overview of the current state of the art. These studies, as well as reports from individual cities, are used to develop an inventory of potential maintenance actions for bicycle and pedestrian facilities including cost and duration. Furthermore, some of these studies focus on one specific measure of performance, for example, condition, safety, or risk, while others use multi-criteria optimization that demonstrate how to structure the problem.

However, there are significant gaps in the literature. Specifically, condition assessment processes for bike and pedestrian facilities are not rigorous and there are few deterioration models; the relationship between the demand for non-motorized transportation and the condition of facilities is poorly understood; disruptions to non-motorized transportation facilities due to roadway repair, repaving and resurfacing are ignored; and the response of non-motorized transportation users to disruptions is not understood or modeled despite the potential for creating equity issues.

3. Potential performance measures

Recognizing that transportation infrastructure is a complex sociotechnical system means that the performance measures must capture both the technical and social aspects of the system. Performance measures are key to being able to make decisions that reflect the needs of individuals, connect to community, regional or state-wide goals, and capture the technical attributes of the systems.

Over seventy performance measures were identified from the literature. These can be grouped according to their focus on accessibility, condition, demand, mobility, and safety. Those most relevant to maintenance decisions are shown in Table 1. Missing are sustainability measures.

Table 1 Performance Measures Relevant to Maintenance of Bicycle and Pedestrian Facilities

Type	Examples of Performance Measures	Scale	Source
Accessibility	Population served by walk/bike/transit	Community	Semler 2016
Condition	Markings, Curb ramps, Signage, Signals	Location	Huber 2013
	Extreme heat, Snow and ice, Structural, Distress, Vegetation, Debris	Link	
	Facility maintenance	Community	Semler 2016
Demand	Person throughput, Disadvantaged population served, Volume	Community	Semler 2016
Mobility	Travel time, Trip length, Delay, Level of service, Vehicle miles traveled (VMT)	Community	Semler 2016
	Bicycle LOS, Bicycle travel speed, Pedestrian LOS, Pedestrian space & speed	Segment or Link	HCM 2016
Safety	Crashes	Community	Semler 2016

4. Formulating the problem

Our objective is to identify and schedule maintenance decisions for roadway, bicycle and pedestrian facilities that recognize the physical interdependencies among the performance measures in Table 1 because of the shared right-of-way and the related disruptions that non-motorized users experience. At the same time, there are limited resources for maintenance projects. Maintaining performance while minimizing costs is critical. Projects can be accelerated, bundled, decoupled, or coordinated to consider user impacts, as well as the larger goals of accessibility, condition, demand, mobility, safety, and sustainability.

Given that the budget for bicycle and pedestrian maintenance is very small compared with that for roadway pavements, for a planned set of pavement-related projects, our objective is to determine the relevant sidewalk and bicycle facility maintenance activities and project timings that optimize the performance measures across a community.

To this end, a multi-objective and multi-modal approach is taken in which modal network representations are connected at intermodal connections, here at crosswalks and entry points to separate facilities, such as bikeways. A mathematical formulation is developed on this representation using select performance measures from Table 1 and relevant constraints. Solution of the formulation provides a schedule of improvement actions across modes that maintains minimum serviceability levels on all modes for all user classes and optimally applies any additional resources to balance elective improvements over the various modal users. Improvements can also increase capacity or accessibility for some or all users on one or more modes. The objective balances these improvements against the negative impact of their execution on users. These impacts are both direct and indirect, the latter arising as improvement activities on one mode impact users or subgroups of users of the other modes, The model incorporates user travel decisions under routine and disrupted transportation environments. Solution provides the set of Pareto optimal schedules. A best compromise solution will be identified through an analysis of tradeoffs and consideration of both operator and user perspectives. Quicker, reduced, weighted objective functions will be considered.

5. Data required and example network

To explore alternative formulations and solutions, we assembled data for a modest, realistic example network representative of many small towns with a concentration of alternative modes. The network is based on actual facilities in the business district of Newark, Delaware. The assets are selected roads, sidewalks, bicycle lanes and bicycle paths. The network is modeled by 17 nodes and 50 links. Link attributes include the number of travel lanes and width, pavement condition, bike facilities, sidewalk width, walkability and bikeability score. Origin-destination flows for each node pair during the morning peak are estimated for each mode totaling 15,500 automobile, 380 bicycle and 360 pedestrian trips per hour. The facilities are in good physical condition and are not congested. The majority of the network is wheelchair accessible. Some links are perceived as dangerous on a bicycle, trashcans and debris often impede pedestrians on the sidewalk, and recent reconstruction projects disrupted travel for several months.

6. Anticipated challenges and expected results

The impact of a roadway recent reconstruction of three links of the 50-link network, with significant impacts that cross all three modes (auto, bicycle and pedestrian) was explored. Of those impacted users, travel times for automobiles and bicycles increased by about 6%. Travel times for pedestrians increased from between 12 and 23% depending on how the user navigated around the construction (moving to a different side of the street or taking an alternative route). Additionally, non-motorized modes experience 22% of the total delay but are only 5.5% of the users. This preliminary analysis demonstrates that non-motorized modes experience a disproportionate share of the disruption. In the past, disruptions, as well as the different perspectives of the mobility-impaired or commuters versus recreational users, have not been considered when planning, scheduling, and implementing maintenance activities.

To capture this, we plan to build on the existing literature on transportation project optimization/prioritization and performance measures for roadways, sidewalks, and bikeways, recognizing the different needs of the roadway user, pedestrian, and cyclist. The objectives and constraints of this project recognize the user needs (safety, travel time reliability, bikeability and walkability, desired level of service), agency needs (available funds, activity durations, available equipment, project quality), environmental sustainability (CO2 emission) and social sustainability (equity, accessibility, and mobility). A clustering algorithm (K-means, hieratical clustering, or other machine learning algorithm) will be developed to bundle (optimize/sequence) maintenance activities considering multiple objectives. Trade-off analysis will be conducted by selecting different objective-related activities for bundling using the developed algorithm. In the end, we expect to provide practical recommendations for sequencing the roadway, sidewalk, and bikeway activities to maximize the pre-determined objectives. The trade-off analysis may help identify the key factors that impact the achievement of the objectives.

Some of the challenges we anticipate include dealing with the different spatial and temporal scales. Unacceptable distress levels, physical barriers, poorly timed traffic signals, or poor pavement markets can disrupt a pedestrian or bicycle trip at any time, but maintenance may only be undertaken once per year. Alternative paths are dependent on safe intersections that may not be timed to cater to non-motorized users.

Our plan is to provide a sense of the order magnitude of disruptions and the key factors that influence performance to be able to assemble guidelines suitable for local governments that most commonly manage these facilities.

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