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Gerardo W. Flintsch · Eugene A. Amarh · John Harvey · Imad L. Al-Qadi · Hasan Ozer · Davide Lo Presti *Editors*

Pavement, Roadway, and Bridge Life Cycle Assessment 2024

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Springer

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Preface

An increasing number of government agencies, academic institutes, and industrial organizations are embracing the principles of sustainability in managing their activities. Life cycle assessment (LCA) is an approach developed to provide decision support regarding the environmental impact of industrial processes and products. LCA, which is undergoing continued improvement, is being implemented worldwide, particularly in the areas of pavement, roadways, and bridges. This includes standardization of practice, better alignment with international norms in other fields, resolution of gaps in data and technical approaches, and greater understanding of LCA advantages and challenges in assist decision-makers.

The International Symposium on Pavement, Roadway, and Bridge Life Cycle Assessment 2024 provided a forum for sharing and discussing experiences and results, assessing status and plans for implementation, discussing solutions to challenges, and identifying the extent of consensus on current issues. This symposium was organized by Virginia Tech. The symposium is a follow-on to the 2010 Pavement LCA Workshop in Davis, California; 2012 RILEM Symposium on LCA for Construction Materials in Nantes, France; 2014 Pavement LCA Symposium in Davis, California, Pavement Life-Cycle Symposium 2017 in Champaign, Illinois, and Pavement, Roadway, and Bridge Life Cycle Assessment 2020 held on line.

The symposium brought together academic and industrial leaders from around the world. Over 100 papers were submitted to the conference and selected papers are included in these proceedings. Each paper has been peer-reviewed by at least three professionals in this field. Based on the reviewers' recommendations, the papers that suited the conference goals and objectives were included in the proceedings. The proceedings papers cover various research and practical issues related to pavement, roadway, and bridge LCA, including data and tools, asset management, environmental product declarations, procurement, planning, vehicle interaction, and impact of materials, structure, and construction, as well as emerging topics on social life cycle assessment.

The technical program of the symposium consisted of keynote speeches, short invited presentations on key topics, approximately 50 oral presentations of papers, posters, and panel discussions. The symposium was developed in consultation with government and industry advisors and a scientific committee of over 45 members. The organizers of the symposium acknowledge the efforts of all members of the scientific committee whose help has vastly contributed to the success of the symposium. We are thankful for all those who volunteered their time to thoroughly review the submitted papers and offer constructive comments to authors.

Gerardo Flintsch
John Harvey
Imad L. Al-Qadi
Hasan Ozer
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Quantitative Measures of Social Sustainability for Pavements: Future Directions for Implementation

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Abstract. Pavement sustainability requires balancing economic, environmental, and social factors. However, the social aspect is often less studied and harder to measure, making its integration into life cycle approaches complex. Recent policies like the Justice40 initiative and the Bipartisan Infrastructure Law have highlighted the necessity for fair infrastructure, emphasizing the importance of concrete social sustainability measures. Current methods like social life cycle assessment (S-LCA) tend to concentrate more on social governance and human well-being, rather than providing a tangible measure of how pavement investments affect individuals. This research summarizes a new method to measure the effects of road conditions on marginalized groups, particularly environmental justice (EJ) communities. It stresses the need to include social factors in assessing pavement sustainability. This approach evaluates the impact of road conditions on both EJ and non-EJ community members and road users. It examines fuel usage during commutes in relation to pavement quality in these areas. Finally, the study discusses future research directions for the methodology's usage in life cycle frameworks such as LCA and LCCA.

Keywords: Social Sustainability · Environmental Justice · LCA · LCCA · S-LCA

1 Introduction

Transportation significantly contributes to greenhouse gas emissions in the U.S., accounting for approximately 29% of total emissions [1]. Pavements, essential for supporting both freight and personal vehicles, are integral to the sustainability of the transportation system [2, 3]. Pavement sustainability encompasses a broad range of objectives, including achieving engineering goals, preserving ecosystems, using resources economically, and meeting basic human needs such as health, safety, equity, employment, comfort, and happiness [4]. This concept aligns with the triple bottom line approach, which focuses on economic, environmental, and social sustainability [5].

While the economic and environmental dimensions of pavement sustainability have been extensively studied and can be quantified through methodologies like life cycle

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cost analysis (LCCA) and life cycle assessment (LCA) [6–8], the social aspect remains relatively understudied. Assessing social sustainability requires developing metrics to quantify the impact of pavement design, rehabilitation, and maintenance decisions on communities, especially those disproportionately facing negative impacts [9–14]. This study builds upon recent work in pavement sustainability and transportation equity by focusing on disadvantaged communities that are often burdened with poor road conditions and by exploring methodologies to quantify their impact during essential recurring trips, such as home-to-work journeys.

2 Goal and Scope

This paper summarizes a methodology [15] that quantitatively describes and measures the impact of road conditions on vulnerable communities, emphasizing the importance of considering the social component in pavement sustainability assessment. Finally, future research directions are discussed for follow-up studies. Massachusetts served as the case study area. The methodology aims to integrate social sustainability considerations into existing life cycle methodologies. The outline of the study is as follows:

1. Summary of Okte et al.'s [15] methodology
   a. Obtaining pavement condition from Massachusetts geoDOT
   b. Overlaying pavement condition with vulnerable communities
   c. Matching communities to their work locations to find recurrent trips
   d. Comparing the pavement condition and fuel consumption within and outside EJ communities to assess if the pavement infrastructure serves everyone equally
2. Discussion of implementation for future studies

3 Methodology

3.1 Defining Vulnerable Communities (EJ for Massachusetts)

Environmental justice (EJ) communities in Massachusetts were defined using specific criteria set by the Massachusetts Department of Transportation (MassDOT), based on U.S. Census data. Under these criteria, a community is identified as an EJ community if it meets any of the following conditions: the annual median household income is 65% or less of the statewide median, minorities comprise 40% or more of the population, 25% or more households have limited English proficiency, or minorities make up 25% or more of the population in a municipality where the median household income does not exceed 150% of the statewide median [16, 17].

3.2 Assessing Road Conditions and Excessive Fuel Consumption

In assessing road conditions in Massachusetts, the study used the Present Serviceability Index (PSI) to evaluate 5967 miles of state-owned roads. The PSI, a measure of road quality based on factors such as cracking and rutting, ranges from 0 to 5, with higher values indicating better road quality. Roads were categorized as excellent, good, fair, or poor based on their PSI scores. To quantify the impact of road conditions on travel, the study employed the International Roughness Index (IRI), a measure of road roughness. By converting PSI values to IRI, the study estimated excessive fuel consumption due to varying road conditions, particularly focusing on their impact on EJ and non-EJ communities in Massachusetts [18, 19]. Figure 1 summarizes this analysis.

3.3 Analyzing Home-to-Work Trips

Home-to-work trips in Massachusetts were analyzed using the LEHD Origin-Destination Employment Statistics (LODES) from the U.S. Census Bureau, focusing on the main trips of residents living and working within the state as of 2019. This data, encompassing approximately 3.02 million trips by over 3.31 million people, identified residents in EJ block groups as part of EJ communities. The study constructed a road graph to find the shortest travel paths, excluding trips under 5 miles to focus on those likely taken by personal vehicle. The analysis then calculated the excessive fuel consumption [19] for these trips, comparing the impact on EJ and non-EJ communities. Figure 2 provides an example trip calculation.

4 Assumptions and Limitations

The study assumed that all trips follow the MassDOT managed road network, acknowledging that while local roads outside of MassDOT jurisdiction exist, most trips longer than 5 miles are likely to include major routes and interstates. Another assumption was that all trips over 5 miles were possible by personal vehicle, noting that the LODES data do not include travel mode information, thus precluding the separation of personal vehicle trips from public transportation. Lastly, the study recognizes that there are multiple user impacts such as maintenance, repair, and tire wear-and-tear that are influenced by

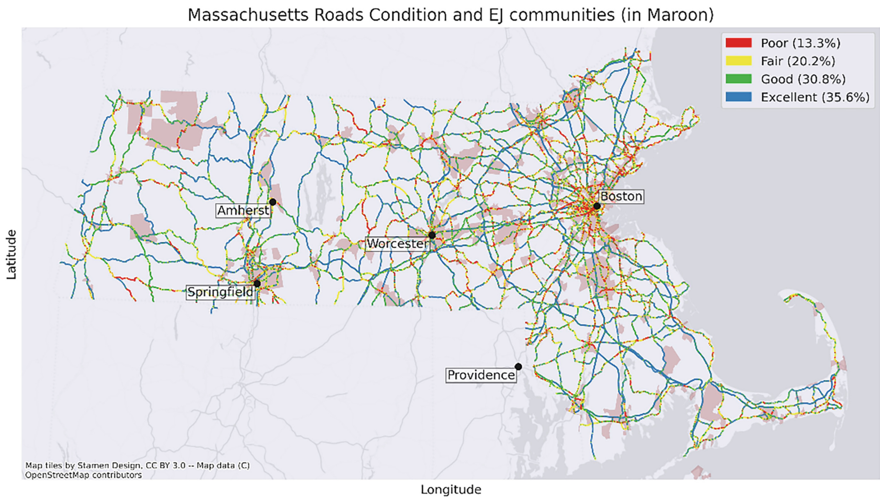

Fig. 1. EJ communities overlaid with road condition in Massachusetts.

factors like IRI, vehicle type, and localized distresses like potholes. In this study, however, only energy consumption was utilized as an indicator to demonstrate the impact of road condition on users as an illustrative example [20, 21].

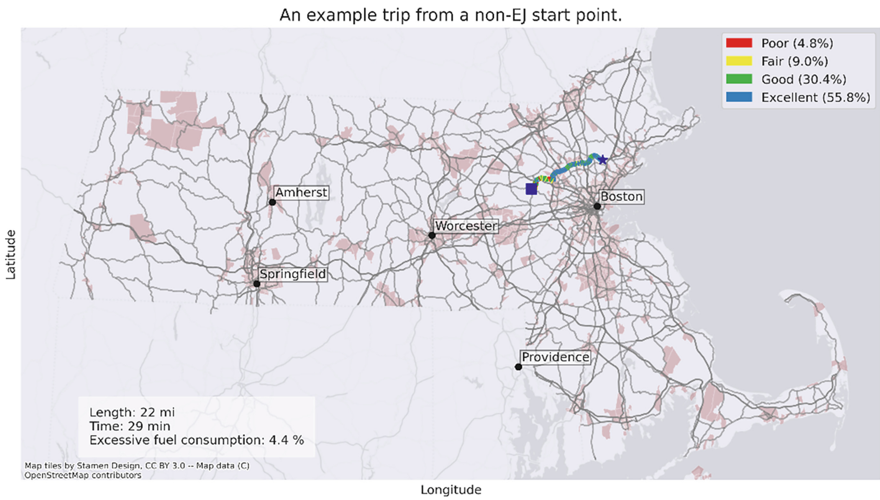

Fig. 2. Example of home-to-work trip calculation.

5 Summary

This study summarizes a methodology for evaluating the disproportionate impact of road conditions on disadvantaged communities, highlighting the need for metrics to quantify these inequalities [15]. Findings indicate that within the entire state of Massachusetts, EJ communities are nearly twice as likely to live near poor roads and consume up to twice as much excess fuel due to road conditions.

6 Future Work

6.1 Vulnerable Community Definition

There are various future research directions. First, it is crucial to define vulnerable communities of interest. For instance, although EJ was used for Massachusetts, different states may use different definitions of vulnerable communities. Moreover, because vulnerable communities are usually a collection of different categories, it may be crucial to look at different subcategories. For instance, Fig. 3 shows the different EJ categories based on the definition of EJ communities in Massachusetts. Depending on the priorities of the analysis type, a study could focus on one or more EJ categories.

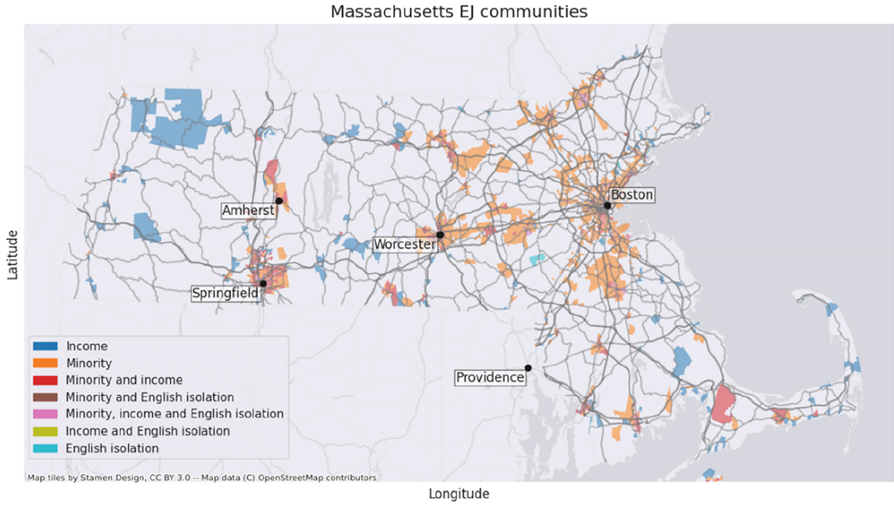

Fig. 3. Massachusetts EJ categories.

6.2 Definition of Study Area

This analysis is, by default, a network-level analysis. Therefore, it is critical to define the study area based on the responsible agency. For instance, this analysis could be conducted at a higher granularity for a township, but then the focus should be on the roads that that township is responsible for maintaining, similar to pavement management systems. It is also crucial to engage the responsible agency during or prior to analysis to better understand their needs and priorities. For instance, while this study used public MassDOT datasets to introduce a methodology, future studies may engage MassDOT to determine their specific goals/study areas for implementation of this framework.

6.3 Investigation of Other Impacts

This study focused on road condition and additional fuel consumption as proxies for social sustainability. However, there could be other metrics of interest that an agency analyst may be interested in. For instance, this study used categorized road condition (poor, fair, good, excellent) as measures. However, pavement condition is usually on a continuous scale, as shown in Fig. 4. Categorizing the measures may hide existing trends in the distribution.