Analysis for the sustainability of intelligent transport systems in the United States

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Abstract. The economic, social, and ecological wellbeing of a society are all negatively impacted by the traffic congestion issue. Intelligent Transportation Systems (ITS) have been used to better sustainable transportation systems across the globe, helping to lessen the unsustainable effects of the clogged highway issue. The goal may be reached by examining the positive effects ITS deployments have had on urban areas in the United States. In addition to the statewide findings, we also do in-depth research on the economies of seven major Florida communities. A fuzzy-data envelopment analysis (DEA) technique is used instead of the conventional DEA approach for sustainability performance analysis in order to take into account the uncertainty in benefit and cost evaluations. While all of the ITS investments are very successful when looking at the cost-benefit ratio, the findings from the fuzzy-DEA method show that some of them are less efficient than others. This research's TBL findings give a fuller picture of the societal and economic benefits of ITS-related congestion reduction, including its drawbacks, indirect indicators, and environmental advantages. In addition, decision makers had positive findings from TBL analysis of ITS initiatives and comparisons of sustainability performance of ITS investments. Keywords: Cost Benefit Analysis, Life Cycle Assessment, Data Envelopment Analysis, Sustainability.

1 Introduction

Road congestion in the United States is mostly caused by an increase in population, the number of cars on the road, and the number of vehicle miles travelled (VMT). Countless reports over the last decade have shown the seriousness of the traffic congestion issue according to (Febriani et al, 2020; Ushakov, 2022a; Dudukalov et al., 2020). For instance, in 2011, yearly VMT in the United States hit 2.97 trillion miles, a rise of 8% from before the 2008 financial crisis.

Therefore, it's evident that traffic congestion is bad for business, the environment, public safety, and society as a whole. The Texas Transportation Institute (TTI) estimates that congestion cost the United States $121 billion in 2011 due to an increase in travel time of 5.5 billion hours and an increase in fuel consumption of 2.9 billion gallons. That means the

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average American commuter throws out $922 and 20 gallons of gas per year in addition to wasting 43 hours of their time according to Takayama et al (2020).

Efforts are being made all around the globe to alleviate traffic congestion and construct more environmentally friendly transportation networks by a wide range of academics, think tanks, and government agencies. According to Kraus & Proff (2021) as a result of this issue, most people agree that it is no longer possible to use resources at the same pace as before, and that time is running out for us to do anything about it.

These findings suggest that transportation networks might benefit from the use of sustainable development strategies. According to Serrano-Hernandez et al (2021) "sustainable development" is the "creation of a development which satisfies the demands of the present without compromising the capacity of future generations to satisfy their own needs." For transportation networks, this means making sure that future generations' access to mobility and transportation isn't limited in any way according to (Gutiérrez et al., 2022). Despite the continued efforts of researchers, governors, decision makers, etc., no major progress has been made in creating a more sustainable world or sustainable transportation systems.

Sustainable development is not a simple topic to grasp since it is measured in several ways. To provide only a few examples, transportation has an impact on things like fossil fuel (petroleum) reserves, the global atmosphere, local air quality, noise pollution, accessibility, congestion, and death rates according to (Ushakov et al., 2021a; 2022b, Hoonsiri et al., 2021). A trillion and a half million barrels of oil have been used thus far. This may help to illustrate the gravity of the situation by itself. It's fair to wonder whether the world's oil reserves will be sufficient to fulfill the demands of future generations, given the current pace of population increase and the rising number of cars on the road.

Traffic congestion and overall accessibility are both negatively impacted by rising vehicle miles travelled and vehicle numbers according to (Karjalainen & Juhola, 2021; Ushakov, 2022b). Congestion on the roads is a common complaint among city dwellers nowadays according to Ghaffar & El Aziz (2021). Local government agencies also spend vast sums of money trying to expand roads and lessen traffic, but so yet, the results have not shown any signs of meaningful improvements since the roads cannot be extended to infinity. In addition, traffic jams are a major contributor to poor air quality in cities because of car emissions. In a worldwide context, transportation is a major contributor to poor air quality according to (Kozlova et al., 2021; Ushakov et al., 2021, Ren et al, 2020).

Poor air quality is a global problem that endangers all forms of life, not just human beings. Moreover, since automobiles consume fossil fuels, emissions and world average temperature are also rising. Finally, another problem that should be addressed as part of sustainable development is traffic accidents. The World Health Organization (WHO) reports that approximately 1 million people are killed and almost 70 million are injured worldwide due to traffic accidents every year. Over the last decade, the U.S. has seen a decline in its fatality rate per 100 million vehicle miles travelled (VMT), from 2 to 1.25. Federal efforts to strictly enforce existing traffic rules and introduce new ones have contributed to a dramatic drop in accident rates over the last decade. Every accident has a heavy financial toll on society according to Tang et al (2020) and Al Shaher et al. (2022).

Because of these unsustainable transportation practices, it is critical to find innovative ways to slow down the industry's forward momentum according to (Sultana et al, 2019; Ushakov et al., 2022; 2022a). Because halting or becoming sustainable is impossible beyond the point of utopia, the term "deceleration" is more appropriate for the present predicament. In today's research, changes in perspective as diverse as technology advancements, commuting habits, alternative fuels, etc. In addition to the usual economic and environmental worries, these shifts may have other fascinating repercussions for society according to Tan & Ismail (2020).
2 Cost-Benefit Analysis of Intelligent Transportation Systems

In their research on the effects of transportation systems, according to Hamurcu & Eren (2020) identify four distinct approaches: profile and checklist assessment, scoring, cost-benefit analysis, and mathematical programming. This research is based on cost-benefit analysis methods and is meant to feed into multi-objective efficiency modelling.

As part of a National Cooperative Highway Research Program (NCHRP) initiative in 2002, Cambridge Systematics looked into the economic, environmental, social, and safety advantages of alleviating congestion without taking indirect industrial consequences into account. Stokes & Seto (2019) completed a cost-benefit and economic effect analysis of ITS installations in 2013. The indirect monetary and ecological effects were overlooked in this investigation.

Many various types of ITS applications are examined in this book, including Commercial Vehicle Operation (CVO) by Karjalainen & Juhola (2019), IT systems by (Mahmoudi et al., 2019), and public transportation by Reyes-Rubiano et al (2021).

Furthermore, Linton et al (2014) conducted a macro-level analysis of the costs and advantages of ITS. Surface Transportation Efficiency Analysis Model (STEAM) is a decision support tool created by the Federal Highway Administration (FHWA) of the United States that is used by national and regional transportation authorities to put a price on infrastructure and calculate its benefits.

Furthermore, the United States Department of Transportation (DOT) has compiled reports detailing the cost, benefit, and lessons learned from various ITS implementations in the United States according to Cohe (2009).

3 Life Cycle Assessment of Intelligent Transportation Systems

Sugrue & Adriaens (2022) created a method called life cycle assessment (LCA) to study the environmental effects of complex systems. In other words, it is a robust approach that has been frequently utilized in the literature to provide outcomes of cradle-to-grave effects of production or process. This "cradle to grave" methodology begins with sourcing raw materials and continues through the manufacturing, distribution, and disposal stages. Goal and scope definition, life-cycle inventory analysis, life-cycle impact assessment, and interpretation are the core components of LCA methodology. Supply chain effects, such as those on the economy and the environment, may be analyzed with the use of the LCA technique and Economic Input-Output (EIO) analysis.

The Green Design Institute at CMU created the EIO-LCA tool, and it has been frequently cited in the literature since its release. The breadth of its use throughout the literary canon spanning building and engineering to transportation and medicine to agriculture and beyond—attests to the effectiveness of this method according to Al Hurr & Tashman (2019). In addition to Environmental Impact and Optimum Level of Care Assessment (EIO-LCA), Ecologically-based LCA (Eco-LCA) was developed by the Ohio State University's Centre for Resilience to analyze the function of ecological products and services in manufacturing according to Tao et al (2019).

Thomas et al (2016) used the Eco-LCA technique to the building sector. Hassan et al (2018) analyzed the mass, energy, and ecological exergy of resource use across building industries in the United States. The Triple Bottom Line (TBL) based LCA model might be presented as an acceptable approach since it incorporates economic and social indicators into EIO technique while also drawing environmental burdens, something that neither EIO-LCA nor Eco-LCA can achieve. Indicators of economic and social sustainability are increasingly being included into LCA framework in response to the demand for more comprehensive study of the consequences of sustainability.
Further, (Huh & Kim, 2019) suggests that this pattern sparked the development of Life Cycle Sustainable Assessment (LCSA). Incorporating Life Cycle Cost (LCC) and Social Life Cycle Assessment (SLCA) methods helps to generate the TBL concept, which in turn contributes to sustainability across the three main dimensions of environment, economy, and society. Baker Al Barghuthi & Togher(2020) original EIO-based TBL model encompasses all of Australia's manufacturing and mining industries. In this method, the Australian economic sectors' EIO tables are combined with the three most important sustainability indicators (environmental, economic, and social). More than that, academics at the University of Sydney used this fundamental TBL approach to create the Balancing Act program for the economies of Australia, the United Kingdom, and Japan. TBL has been used in a number of published research, including those by Uddin, (2016). Liu et al (2021) provide the first research to use TBL technique to analyze the effects of the construction industry on the U.S. economy. In addition, the direct and indirect socioeconomic and environmental implications in Florida are shown by this method, which was first used to an ITS research and reported by according to Takayama et al (2020).

4 Data Envelopment Analysis (DEA)

The technique is used by some mathematical programming models to compare the efficacy of a group of similar entities, or "Decision Making Units" (DMUs). The paper looked at how to evaluate ITS performance and how to apply DEA to transportation issues, down to the nitty-gritty of the technique. Fuzzy set theory was developed as a solution to the issue of imprecision and ambiguity in the definition of problems encountered in the actual world. A key finding of his research was the value of linguistic factors in complex settings with high degrees of uncertainty. Some of the numbers used in DEA analysis are prone to imprecision or vagueness. The Serrano-Hernandez et al (2021) model was the first to use fuzzy set theory and uncertainty levels.

There are four distinct approaches to DEA's use of fuzzy set theory: the tolerance method, the -level based approach, the fuzzy ranking approach, and the possibility approach. The amount of published research using the -level method makes it one of the most popular models. The fundamental algorithm used in the -level based fuzzy DEA method was created by (Karjalainen & Juhola, 2021). In BCC-DEA (BCC is due banker) they take a different tack by transforming fuzzy data into a crisp model that can be used to evaluate the effectiveness of the DMU. Specifically, it calculates the lower and upper fuzzy efficiency scores for a given -level.

4.1 Data Description

Table 1. Comparison between Congestion and ITS benefits.

<table>
<thead>
<tr>
<th>Regions</th>
<th>ADH</th>
<th>AEFH</th>
<th>TCC</th>
<th>ADR</th>
<th>FS</th>
<th>ACCS</th>
<th>DRCS</th>
<th>FRCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>New-York</td>
<td>35,260</td>
<td>11,236</td>
<td>823</td>
<td>2,123</td>
<td>612</td>
<td>48.1</td>
<td>45.31</td>
<td>1.23</td>
</tr>
<tr>
<td>Chicago</td>
<td>13,236</td>
<td>12,336</td>
<td>512</td>
<td>1,369</td>
<td>639</td>
<td>47.3</td>
<td>41.3</td>
<td>14.12</td>
</tr>
<tr>
<td>Boston</td>
<td>7,400</td>
<td>1,321</td>
<td>153</td>
<td>1,236</td>
<td>313</td>
<td>48.3</td>
<td>41.9</td>
<td>14.3</td>
</tr>
</tbody>
</table>

The gathered data is summarized in a table that details three cities' yearly delay hours, lost fuel due to traffic congestion, and savings attributable to ITS expenditures. We utilized 2010 CPI data ($56.30 per person/hour and $89.12 per commercial vehicle/hour) to determine the cost per delayed hour.

The full effect on the economy and society at large must be determined in order to make informed policy decisions about how to invest these savings. The full effect of these cost
reductions on the economy and society must be determined. While ITS helps reduce fuel import costs, it has a negative impact on petroleum refineries and governments by lowering profits, jobs, and tax revenues.

4.2 Efficiency Rankings

<table>
<thead>
<tr>
<th>ITS Applications</th>
<th>SPI-1 (LB)</th>
<th>SPI-1 (UB)</th>
<th>SPI-2 (LB)</th>
<th>SPI-2 (UB)</th>
<th>SPI-3 (LB)</th>
<th>SPI-6 (UB)</th>
<th>Overall SPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freeway Management</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Incident Management</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Traveler Information</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Automated Highway System</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Arterial Management</td>
<td>0.75</td>
<td>1</td>
<td>0.55</td>
<td>1</td>
<td>0.41</td>
<td>1</td>
<td>0.71</td>
</tr>
<tr>
<td>Commercial Vehicle Operation</td>
<td>0.33</td>
<td>0.41</td>
<td>0.30</td>
<td>0.54</td>
<td>0.21</td>
<td>0.60</td>
<td>0.30</td>
</tr>
<tr>
<td>Electronic Toll Collection</td>
<td>0.11</td>
<td>0.20</td>
<td>0.10</td>
<td>0.23</td>
<td>0.08</td>
<td>0.28</td>
<td>0.14</td>
</tr>
</tbody>
</table>

As seen below, the benefit-to-cost ratio has no impact on the efficiency ratings. Comparatively, the automated highway system gives a benefit/cost ratio of 3.01, making it one of the most efficient systems, whereas the least efficient instances (commercial vehicle operation and electronic toll collection) of this research result in 15.35 and 3.18, respectively. The benefit-cost ratio has little impact on efficiency ratings, as is evident from the data.

5 Summary of Findings

Increasing traffic congestion has a detrimental effect on people's everyday lives. One method that aims to lessen traffic congestion while also improving the economy, the environment, and public safety is the implementation of Intelligent Transportation Systems (ITS). It is critical to show the effects of new ITS investments on transportation infrastructures from a holistic perspective in order to persuade decision makers to go forward with them.

Finally, we compared the sustainability performance of the reference ITS investments. Three populous cities have adopted a TBL strategy based on an input-output model. As a consequence, not only were their national economic (profit, employment, tax income, import) and environmental (GHG emissions, energy and water consumption, hazardous releases to air, ecologic footprint) effects calculated, but so were their savings due to delay reduction and fuel savings. This study included data from U.S. metro areas over the course of four years.

The findings of this research highlight the significance of investigating the indirect effects of the supply chain on cost reductions. In most cases, the value of indirect indicators is within a small margin of the value of direct indicators. Because not all socioeconomic variables show positive effects, the most important conclusion drawn from this TBL method research is that it leads to significant "net" savings in certain areas. There are some drawbacks to ITS,
but overall it has many favourable effects. Total sustainability advantages of ITS over 4 years are substantial, yet they are insufficient to alleviate traffic congestion on their own. Congestion relief can only be achieved using ITS as part of a larger "sustainable transportation" strategy.

Using the same coefficient units, the cost and benefit components are transformed to similar fraction units so that an exact efficiency analysis may be provided. The time, pollution, and risk reduction advantages add up to substantial financial savings. The purpose of this research is to compare the efficiency outcomes with the benefit-to-cost ratio of ITS investments. Three of the ITS applications were determined to be inefficient after taking into account uncertainty scenarios for O&M costs and benefits.

6 Limitations

The findings of this research were derived from the TTI Urban Mobility Report, namely the report's free-flow trip time and travel time index values. Congestion alleviation effects of ITS in locations with accessible detectors are exclusively studied in relation to freeway ramp metering, incident management, traffic signal coordination programs, arterial street access management programs, and High Occupancy Vehicle (HOV) lane applications. Furthermore, the data only accounts for ITS deployments in metropolitan settings. Rural regions might be included in the whole picture of the ITS benefit study in the United States.

Therefore, the total effects of ITS implementations in cities may exceed those estimated here. Seven diverse applications in the United States serve as the basis for an investigation of the sustainability performance of ITS investments. It was challenging to locate complementary reference studies that use the same benefit calculation approach. Additionally, the restriction of sustainability performance analysis was the absence of information regarding the precise cost and benefit analysis of ITS investments.

7 Future Studies

As a result, our technique allowed us to quantify the direct and indirect effects of ITS systems on sustainability. More sustainability metrics may help expand this research. Using this novel in-depth and 80-holistic strategy, we can compare the effects of ITS with those of new road building with regards to congestion.

This means that the effectiveness of various implementations in easing congestion might be useful to policymakers.

Further, if additional DMUs were included in the sustainability performance analysis, the study's scope may be expanded to provide more detailed findings concerning ITS investments.

8 Conclusion

Intelligent Transportation Systems (ITS) may help implement the sustainable transportation approach's proposed techniques for addressing existing challenges in the transportation sector. Intelligent transportation systems (ITS) combine technology upgrades to a road system with upgrades that boost the system's efficiency. Intelligent transportation systems (ITS) are a potential remedy with the potential to improve transportation in a number of ways, including with regards to fuel efficiency, accessibility, operational efficiency, pollution, and safety. Basically, the purpose of ITS is to make people's lives better in some way.

Reduced congestion, improved air quality, and increased safety are just some of the issues that may be addressed by ITS. ITS cover a wide range of topics, from advanced traffic
management systems (like freeway and incident management systems, electronic toll collection) to advanced traveler information systems (like dynamic message signs and in-car real time traffic information and navigations systems) to advanced public transportation systems, and even commercial vehicle operations.

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