AN EVALUATION OF THE FEDERAL HIGHWAY ADMINISTRATION'S TOOL FOR OPERATIONS BENEFIT/COST ANALYSIS

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ABSTRACT

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Traffic congestion is increasing as more people travel for work-related and other reasons. Through transportation projects called active traffic management (ATM) strategies, transportation agencies work to alleviate the pressures of congestion on the roads. Transportation agencies analyze these project's effectiveness through a cost-benefit analysis spreadsheet tool called the Tool for Operations Benefit-Cost Analysis (TOPS-BC). In this study, the TOPS-BC tool is compared to cost-benefit analysis best practices. The US-23 Flex route, an 8.5 mile stretch of Michigan's US-23 from Ann Arbor to Whitmore Lake, will be used as an example project. The missing categories found in the literature were impacts on road ecology and nearby housing values. These missing categories will help lead to a more accurate benefit-cost ratio of projects like the Michigan US-23 Flex route.

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CHAPTER 1. INTRODUCTION

As more people travelled for personal or work-related reasons, traffic congestion significantly increased in the United States (Levecq et al, 2011; Asif-Khan et al, 2017). Transportation departments have access to limited resources to solve this problem. Active traffic management (ATM) techniques such as those deployed in Europe may offer possible solutions (Mirshahi et al, 2007). ATM techniques manage congestion by 'monitoring current and predicted conditions' (Poulopoulou and Spyropoulou, 2019, 412). Three United States' research groups, funded by the Federal Highway Administration (FHWA), toured Europe. The first group observed European demand management strategies while the other two groups focused specifically on ATM. The researchers noted ATM techniques' effectiveness (Mirshahi et al, 2007; FHWA, 2020g). In the US, these techniques are used in isolation or together to mitigate congestion.

The subject of the current study is an 8.5 mile stretch of US-23 from Ann Arbor to Whitmore Lake, MI. On US-23, a set of four ATM techniques are implemented together to reduce congestion. Throughout the thesis, the term 'Flex route' is used to refer to the entirety of the 8.5 mile stretch. When the term Flex lane is used, it refers to the left shoulder only when the Flex is open. The four techniques included are hard shoulder running, variable speed limits, queue warning, and lane use control systems (Palmer, 2017). The Flex route officially opened for public use on November 15, 2017 between Ann Arbor and Whitmore Lake. In building the Flex route, the Michigan Department of Transportation officials sought to reduce the number of bottlenecks in an area of the state known for its high level of congestion (Frank, 2017). The left shoulder operates during morning and afternoon peak periods, special events and crashes

(Michigan Department of Transportation, 2016). The Flex route will be used as an example transportation project to analyze the gaps in the FHWA cost-benefit analysis spreadsheet tool.

Analyzing the Michigan Flex route is necessary because it can be used to determine what may be missing from the FHWA's cost- benefit analysis spreadsheet tool. The FHWA tool, or the Tool for Operations Benefit Cost Analysis (TOPS-BC), evaluates the economic feasibility of transportation projects. The spreadsheet tool can calculate a benefit to cost ratio of each active traffic management strategy implemented in the United States. To do this, it calculates the costs and benefits separately using data parameters. The current version will be analyzed and compared against cost-benefit analysis best practices. The ATM strategies implemented on the Michigan US-23 Flex route provide an example of a transportation project that can be analyzed with the new cost and benefit categories.

The goal of the study is to suggest improvements to the FHWA cost-benefit analysis spreadsheet tool. The alterations to the spreadsheet tool will provide a more accurate idea of the costs and benefits of transportation projects.

There will be a more accurate benefit-cost ratio than predicted in past analyses because of the use of additional data not already considered. The study is limited to identifying which categories are not incorporated in the FHWA's cost-benefit analysis spreadsheet tool provided to state agencies to accurately reflect cost-benefit ratios.

Chapter 2 is a review of the literature of ATM techniques, best-practice cost-benefit analysis, and the new ways to analyze those techniques. Chapter 3 describes the FHWA spreadsheet tool in depth. Chapter 4 analyzes how the spreadsheet tool could be updated based on best practices. Different costs and benefits are added to the existing spreadsheet tool. The chapter also includes details from the results of the analysis and provides a comparison between cost-benefit analysis best practices and the current capabilities of the tool. Chapter 5 discusses why the new data should be added to the tool. Chapter 6 concludes the thesis with how the FHWA can use the results to evaluate future Flex routes.

CHAPTER 2. LITERATURE REVIEW

2.1 Active Traffic Management Techniques

As metro areas have expanded, more congestion locally and within surrounding cities occurred. Congestion continues worsening as population is growing (Levecq et al, 2011). People are travelling more for their jobs and personal reasons (Asif-Khan et al, 2017). Because congestion became a major problem, researchers in Europe began to study ways to reduce congestion without widening the highways (Levecq et al, 2011). Mirshahi et al (2007) visited Germany, the Netherlands, England, Greece and Denmark to obtain information on these countries' policies and programs mitigating congestion through the International Technology Scanning Program, or SCAN, administered by the Federal Highway Administration (FHWA). All five countries used at least one or two types of active traffic management (ATM) techniques. Since then, research in the United States and the rest of the world has demonstrated these techniques' effectiveness (Ma et al, 2016).

Researchers explored the effectiveness of ATM systems within Europe and the United States. Poulopoulou and Spyropoulou (2019) defined ATM techniques as those that 'manage congestion through monitoring current and predicted conditions' (Poulopoulou and Spyropoulou, 2019, 412). Examples of these techniques include hard shoulder running, variable speed limits, queue warning systems, and lane use control systems (Guerriari and Mauro, 2016; Mirshahi, 2007; Chun and Fontaine, 2016). A variety of research points to the definitions of each of these techniques. Hard shoulder running opens one, or both, of the shoulders on a highway during peak commuting times or during accidents or incidents to reduce congestion (Guerriari and Mauro, 2016; Chun and Fontaine, 2016; Hadi et al, 2008).

Hadiuzzaman and Qiu (2013) explained that variable speed limits on highways take account of traffic conditions such as weather and congestion and change the speeds accordingly. The changes in speed limit manage traffic flow, which helps increase capacity. Queue warning systems involve message displays to warn of traffic issues downstream of the display (Sisiopiku, 2012; Mirshahi et al, 2007). The system prevents secondary crashes from congestion (Mirshahi et al, 2007). Lane use control systems (LUCS), defined through research by Chun and Fontaine (2016), are used to direct drivers to a different lane to prevent backups due to a crash or work zone. The systems are often deployed with overhead gantries.

Only three states have implemented a similar collection of ATM techniques to the US-23 Flex route: Virginia, Minnesota, and Washington (Brinckerhoff, 2010; FHWA, 2020g). Virginia is the most similar ATM deployment to the US-23 Flex route because the state implemented the same techniques along with a high-occupancy vehicle lane (Chun and Fontaine, 2016). A key difference is that the Virginia ATM deployment is in a different U.S. region and incorporates hard shoulder running on the right shoulder (with the left used as a high occupancy vehicle lane) (Chun and Fontaine, 2016). The other similar state, Minnesota, is in the same region as the Flex route and incorporates hard shoulder running on the same shoulder. Although the MnPASS system in Minnesota uses hard shoulder running, it is considered a priced dynamic shoulder lane which can be used for a fee by single drivers (Minnesota Department of Transportation, 2020; FHWA, 2012b). The Minnesota Department of Transportation has also incorporated variable speed limits and other technological developments (Kary, n.d.). The Washington Department of Transportation implemented ATM strategies along I-5, such as variable speed limits, signs with road conditions displayed every half-mile, and hard shoulder running on the left shoulder

(Washington Department of Transportation, 2009). The states described incorporated multiple ATM techniques similar but different to those on US-23.

2.2 Cost-Benefit Analysis

Cost-benefit analysis is a well-known method of analysis used for evaluating road projects. Cost-benefit analysis often monetizes the costs and benefits of projects and compares them to future years by discounting them to the present (Self, 1975; Wijnen et al, 2009; FHWA, 2017b). Using a discount rate, discounting converts the future value of money to present values. Future costs and benefits reflect how the value of money changes over time (FHWA, 2012). Rarely does the literature evaluate transportation projects ex-post, i.e. after the project was implemented. They also do not compare the ex-ante and ex-post cost benefit analysis. Some cost benefit analyses use past data to determine if the investment is worthwhile (US Department of Transportation, 2015; Odeck and Kjerkreit, 2019).

Typical projects evaluated are large public ones such as highways, bridges and other important infrastructure (Hussen, 2013; Asif-Khan et al, 2017). The costs include construction and maintenance costs; benefits include time and fuel savings (Willis et al, 1998; Odeck and Kjerkreit, 2019). Cost benefit analysis can be used to evaluate the effectiveness of a road project after implementation or used to pick the best strategy to employ with a limited budget (US Department of Transportation, 2015). A cost benefit analysis is used to analyze the effectiveness of the US-23 Flex route after implementation. Only rarely does the literature (in well-known journals) analyze a transportation project ex-post. That analysis demonstrates the effectiveness of the project and provides evidence for similar projects (Odeck and Kjerkreit, 2019).

2.2.1 Benefits and Costs of Active Traffic Management Techniques

Despite the effectiveness of ATM techniques, there are both benefits and costs. Benefits and costs to ATM techniques include differences in congestion, differences in travel time, reduction in emissions and fuel consumption, differences in safety, and maintenance and construction costs (Geistefeldt, 2012; Kolosz and Grant-Muller, 2015; Wijnen et al, 2009; Hadi et al, 2008; Guerrieri and Mauro, 2016; Evans, 2001; Willis et al, 1998). These benefits and costs determine the impact of ATM techniques on traffic conditions.

ATM techniques are effective at reducing congestion. For instance, Geistefeldt (2012) compared congestion levels before and after the implementation of hard shoulder running on Freeway A5 in Germany. He noticed the duration of congestion reduced from 640 hours northbound and 450 hours southbound to less than 200 hours per year in both directions. Similarly, Guerriari and Mauro (2016) studied the Brenner motorway in Europe. They found a 35 percent increase in capacity going northbound and a 27 percent increase going southbound after implementation of hard shoulder running. Thus, the hard shoulder running strategy reduces congestion and increases capacity.

The effect of ATM on fuel consumption and emissions should also be considered. Kolosz and Grant-Muller (2015) calculated a benefit to cost ratio considering energy, road-side emissions, and vehicular emissions (including traditional cost-benefit analysis inputs) of 5.89 for the ATM system implemented on the M42 in the United Kingdom. They found that ATM contributed environmental and socioeconomic benefits. The socioeconomic benefits included accident prevention and fuel resource savings and the environmental benefit was exhaust emission savings (Kolosz and Grant-Muller, 2015). Other studies' specific focus was on emissions. Examples of common road emissions are NO_x, $PM_{2.5}$, CO, VOCs, and CO_2 (Liu et al, 2017). One study evaluated carbon dioxide levels due to congestion on highways in Southern California. The researchers found a 7-12% reduction in CO2 emissions by implementing congestion mitigation strategies (Barth and Boriboonsornsin, 2008). Reponen et al (2003) collected road traffic pollution data near (50 meters away) and far (up to 1600 meters away) from the interstate highways I-75 and I-71 near Cleveland, Ohio. The researchers found that all emissions, fine particles and $PM_{2.5}$ dissipate more the farther they are from highways (Reponen et al, 2003). Hadi et al (2008) calculated the reduction in road emissions on I-95, I-75, and I-595 in Florida by estimating the average travel speed under incident and no incident conditions. The reduction in emissions is the result of shorter queues (fewer backups). What these studies show is that congestion on highways increases roadside emissions. As Kolosz and Grant-Muller (2015), Liu et al, 2017, Barth and Boriboonsornsin, 2008, and Reponen et al (2003) found, ATM techniques can improve environmental conditions near highways.

The impact on safety is also important when analyzing ATM techniques. Safety refers to the number of crashes/incidents before and after a road project is implemented or in the implementation of road safety policies (Daniels et al, 2019; Wijnen et al, 2019). Wijnen et al, 2009 describes one way to value the impact on safety is by attaching a monetary value to a human life. The Value of a Statistical Life (VOSL) describes what people are willing to pay for a reduction in the risk of death. Individuals value the joy of living because a death would put a strain on their family (Wijnen et al, 2009; Evans, 2001). Daniels et al (2019) evaluated 29 highway safety measures. Monetary values account for the socioeconomic impacts, environmental impacts, one time investment and recurrent costs and impact on the number and type of crashes. Out of the 29 highway safety measures evaluated, twenty-five were cost effective. Fourteen of the 29 were cost-effective under all situations studied. The 14 safety measures' monetary value outweighed the implementation costs (Daniels et al, 2019). Hadi et al (2008) primarily studied an incident management system in Florida of cameras, patrol programs and other technology. The researchers compared several safety functions of the SunGuide operations system in Florida as part of their overall benefit to cost ratio. Their calculations were similar to Daniels et al (2019) when they calculated the costs of several safety performance functions: SIRV, road ranger, CCTV, and ATIS to determine which was the most effective. The researchers overall found the number of incidents and lane blockages detected and managed had increased and calculated an overall benefit to cost ratio of 6.65. Kononov et al (2012) studied the relationship between traffic flow parameters and safety. The researchers obtained crash data for five years from the Colorado Department of Transportation and modeled the relationship using neural networks. At a certain traffic volume, the crash rate increased rapidly (Kononov et al, 2012). Crash rates were also found using police crash reports. These reports provide key figures regarding both primary and secondary crashes and fatalities (Chun and Fontaine, 2016). Chun and Fontaine (2016) used the police crash reports and weighted average annual average daily traffic values (AADT) to determine the crash rate in terms of crashes per 100 million miles of travel (Chun and Fontaine, 2016). The largest improvement in crash rate after ATM strategy implementation was on EB and WB I-66 on weekends (21.51% and 48.05% respectively). The above studies show the safety benefits of implementing ATM techniques on highways.

2.3 New Methods For Cost-Benefit Analysis

Cost-benefit analysis best practices outline which categories should be included and what is the best discount rate. It also highlights the assumptions that must be met for the analysis to be effective. Additional categories to include are all social benefits and non-monetary benefits. Some examples of social benefits include cultural, environmental, and other non-market losses and gains (p. 15, 16, Harrison, 2010). Including those additional categories takes in account indirect effects of high traffic conditions (Vickerman, 2007).

Several other benefit and cost categories exist within the literature, but do not necessarily involve ATM projects. The majority are environmental impacts or road ecology. These impacts are harder to monetize than congestion (Willis et al, 1998). Such impacts include ATM techniques' effect on species richness, the water system, ambient noise levels on birds and amphibians, and increased wildlife fatality rates (Parris and Schneider, 2009; Bee and Swanson, 2007; Consentino et al, 2014). In some situations, people are affected in terms of their health or sleep patterns (Hofstetter and Muller-Wenk, 2005). Effects on the family of the people involved in crashes/incidents on the Flex are another consideration. Families often suffer loss of joy and happiness; some lose the income of the person injured/killed (Evans, 2001; Wijnen et al, 2009). Noise levels from congestion can lower nearby housing values (Ozdenerol et al, 2015; K. von Graevenitz, 2018). These impacts are not always included when evaluating ATM strategies.

2.3.1 Environmental Impacts

Some examples of environmental impacts are effects on wildlife populations and changes in scenic beauty (Boardman et al., 2017). Road ecology also includes noise level impacts on wildlife, increased salt concentration in nearby bodies of water, an increase in deer related crashes, decreases in biodiversity and an increase in invasive species along the edge of the road. There is a chance of an increase in chemicals, such as nitrogen oxides, hydrocarbons and heavy metals, entering the local bodies of water (Forman et al., 2003, 4; Karraker et al., 2008; Halfwerk et al., 2010). Environmental impacts are considered indirect effects in cost-benefit analysis best practices (Boardman et al., 2017; Vickerman et al., 2006; Willis et al., 1998). These impacts are not often included because, “they are not likely to include an accurate assessment of either external or induced traffic effects” (Vickerman et al., 2006, 601).

One study suggested there is an asymmetric road effect zone of 600 meters surrounding major four-lane arterial roads, (similar to the four-lane divided highway of the US-23 Flex Route) where the environmental impacts are greatest (Forman and Deblinger, 2000). The study explained how invasive species were found planted along the edges of Route 2 in the suburbs west of Boston, Massachusetts and then spread into nearby forests. The authors also noted how there were increases in roadkill of amphibians to large mammals (Forman and Deblinger, 2000). To fix this, Rhodes et al, 2014 demonstrated that additional capacity on an existing roadway leads to lower mortality rates on local wildlife than a new road. Researchers studied koalas in Australia using a simulation model of their travel movements and found that mortality rates generally increased with more road density and traffic volume, but road density was found to have the highest impact (Rhodes et al, 2014). Animals also suffered from habitat fragmentation and the high levels of noise (Forman and Deblinger, 2000; Halfwerk, 2010). An example of an organism suffering from habitat fragmentation and high noise levels are birds because they cannot adequately defend their territory or hear potential mates (Halfwerk, 2010; Parris and Schneider, 2009). Parris and Schneider (2009) observed birds in Australia. They found that traffic noise and volume substantively decreased the probability of seeing a gray-shrike thrush and the grey fantail. The grey shrike thrush sang at a higher frequency because of the increase in traffic noise. In comparison, the grey fantail did not change its call. These studies elucidated the impacts of noise levels on surrounding neighborhoods and wildlife population.

Ecosystem services can be addressed in cost benefit analyses even though they cannot be expressly monetized (Rouquette et al., 2009). Ecosystem services are the benefits people obtain from the environment (Seppelt et al., 2011). In a previous study, Balmford (2011) discussed how economic values can be applied to conservation measures. They described how the loss of biodiversity (benefits) can be compared to the associated costs. Folke et al (2004)'s study (as cited in Balmford et al, 2011) found that the resiliency of natural systems and the number of ecosystem services decline with biodiversity from human activity (Balmford et al, 2011). Balmford et al (2011) created a list of 16 key benefits and beneficial processes of environmental systems and then consulted over 50 scientists to create an overall priority ranking of ecosystem services. A citizen science study conducted by Consentino et al, 2014 evaluated roads across the United States. The researchers studied anuran species (frogs) richness and distribution within 200 m from highways. They wanted to assess how these species were impacted by road density and traffic volume, surrounding habitat characteristics, and noise levels. They studied species richness, landscape variables, and species occupancy. Species richness and occupancy were negatively related to road density, traffic, and forest cover, especially within 1 km of sites. The frog species studied travel across the road to get from one place to another. There was no direct effect from noise (Consentino et al, 2014).

2.3.2 Housing Values

Housing values should also be included in a cost-benefit analysis. High noise levels contribute to negative human health impacts, such as annoyance, sleep disturbance, and cardiovascular diseases especially for those people living within a certain distance of a highway (Baudin et al., 2021; Nelson, 2008). The impacts of noise on local housing values can be monetized through people's willingness to pay (WTP) for less noise (von Graevenitz, 2018). Hedonic pricing methods are the most common valuation studies (Navrud et al., 2002). K. von Graevenitz (2018) found that 55 dB is a baseline level because it represents the typical ambient urban noise. As the level of noise increases above 55 dB, the housing prices of those houses within 200 meters from a large road decrease. A large road is one that spans more than six meters across. The researchers also found a variation in preferences and income also affect people's WTP for a noise reduction. The above study indicates that housing values within a certain distance from a road should be incorporated into a cost-benefit analysis of road projects. As Nelson (2008) explained traffic noise also impacts long term health and reduces quality of life. The noise sensitivity depreciation index (NSDI) is useful when describing the impacts of noise on housing values. The index determines how much housing values have decreased for each decibel increase in noise (Nelson, 2008; Navrud et al, 2002). An example is a study by Szczepanska et al, 2015, which analyzed two apartment estates in Olsztyn, Poland: one in the downtown area where the noise levels from traffic were high and another bordered by main roads leading outside of the city. The researchers analyzed 118 apartment transactions with controls for legal status, and apartment condition and structure. The Sródmiescie estate experienced EUR 8.54/m^2 per 1 dBA decrease in noise levels with a NSDI of 0.94%. The Nagórki estate experienced EUR 6.11/m^2 per 1 dBA decrease in noise levels with a NSDI of 0.70% (Szczepanska et al, 2015). What this means is that the Sródmiescie estate, located near a downtown area and on a main transit road experienced more of a depreciation in housing price than the Nagórki estate located on the boundaries of the city (Szczepanska et al, 2015). Ozdenerol et al (2015)'s research also demonstrates the impact of noise on housing values. They modeled noise rings through GIS and calculated noise levels from speed and volume data. The data was inserted into the Department of Transportation's noise prediction model (Ozdenerol et al, 2015). The researchers found that despite different housing characteristics, the increase in noise levels caused a greater decrease in housing values. The threshold was 45 dBA (statistically significant at the 10% level).

2.3.3 Driver Stress Levels

Another key component that should be included in the TOPS-BC tool is driver stress levels and road rage. Congestion and daily events are two of the main contributors to driver stress (Hennessy et al., 2000; Rowden et al., 2010). Combined, they lead drivers to make more mistakes and to become more distracted. Rowden et al. (2010) found through a survey of 247 Australian government officials that daily stress levels were a strong predictor of unsafe driving acts. Because of congestion, drivers will be more likely to drive unsafely.

The current study addresses how to include environmental and other impacts of the Flex route into the FHWA's TOPS-BC analysis tool. TOPS-BC does not currently take account of some impacts on the environment, specifically, increased salinity and chemicals in nearby bodies of water, traffic noise impacts on wildlife, the number of deer-related crashes, and decreased levels of biodiversity. Very few research studies have addressed how to analyze the environmental impacts of ATM techniques (Grant-Muller and Kolosz, 2015). Most studies focused on the general effect of roads on natural areas. They suggested that traffic volume, the existence of the road, traffic and traffic noise are what cause negative impacts (Rhodes et al, 2014; Huijser et al, 2009; Parris and Schneider, 2009; Consentino et al, 2014). The current study discusses which additional costs and benefits should be incorporated into the TOPS-BC tool, based on cost-benefit analysis best practices. The tool will be more effective when assessing the US-23 Flex route and other transportation projects.

CHAPTER 3. METHODOLOGY

The methodology of this study outlines which steps were taken to improve upon the FHWA in their cost-benefit analysis spreadsheet tool. First, the section outlines how the FHWA TOPS-BC tool measures the costs and benefits of the US-23 Flex route in Michigan. Second, the FHWA tool is updated with data categories to accurately measure costs and benefits of the US-23 Flex Route.

3.1 Tool for Operations Benefit Cost Analysis (TOPS-BC)

3.1.1 Description of the Tool

The Federal Highway Administration (FHWA)'s Tool for Operations Benefit/Cost Analysis (TOPS-BC) was used to determine the benefit-cost ratio of the Flex route. TOPS-BC provides support to state transportation agencies in the application of benefit/cost analysis for a wide range of Transportation System Management and Operations (TSM&O) strategies, such as work zone management, interagency coordination, and ATM (FHWA, 2020e). **Appendix 1** lists the TSM&O strategies included in the tool. Transportation agencies adopt the tool to choose the most effective strategy given available resources (FHWA, 2016) or analyze a transportation project already implemented (Reniers et al, 2016; FHWA, 2012).

For example, MDOT implemented four ATM techniques on the US-23 Flex route: hard shoulder running, variable speed limits, queue warning, and lane use control systems (Palmer, 2017). These techniques were matched to strategies covered in the TOPS-BC tool (**Table 3.1**). Each TOPS-BC strategy is evaluated in terms of its benefits and costs with a separate worksheet.

Table 3.1. Determines which strategies from TOPS-BC reflect the four ATM techniques used.

Active Traffic Management Techniques	TOPS-BC Strategies
Hard Shoulder Running	ATDM Hard Shoulder Running, Incident Management, Dynamic Message Signs, CCTV, Traffic Management Center
Variable Speed Limits	[a]ATDM Speed Harmonization, Incident Management, Dynamic Message Signs, CCTV, Traffic Management Center
Queue Warning	Incident Management, Dynamic Message Signs, CCTV, Traffic Management Center
Lane Use Control Systems	Dynamic Message Signs, Incident Management, CCTV, Traffic Management Center

[a]European version of variable speed limits (Levecq et al, 2011)
Source: MichiganDOT, 2017; focus groups; Hadi et al, 2008; FHWA, 2017d; MDOT, 2018; Palmer, 2017; NOCoE, 2019; FHWA, 2020d.

TOPS-BC differentiates data types by color coding individual cells within each worksheet: data maintained in the tool – yellow; data calculated within the tool – blue; optional user defined inputs – light green and bright green; required user defined inputs – bright green. When local data is available, TOPS-BC allows optional user inputs to override default data included in the tool. **Table 3.2** lists some examples of required user inputs, which do not have default values maintained in the tool (FHWA, 2017b).

Table 3.2. Examples of data needed to calculate the benefits of each strategy in TOPS-BC.

Example of Data	Definition
Length of Analysis Period	The period of time in which the strategy operated. Data must match the analysis period.
Capacity	Determined how many cars can be on the highway at once based on the analysis period, highway type and number of lanes.
Volume	Represents all lanes over the analysis period. It also represents the number of vehicles under each vehicle type (autos, trucks).
Free Flow Speed	Average speed of travel in the absence of congestion.

Source: FHWA, 2017b

3.1.2 Costs

The costs of the US-23 Flex route for example, are based on the TOPS-BC strategies implemented there (listed in **Table 3.1**). The costs of projects like the Flex route are listed in ten worksheets in the TOPS-BC tool: "Signal-Preset," "Signal-Actuated," "Signal-Central," "Transit Priority," "ATIS-DMS," "TIM-FSP," "ATDM-Speed," "ATDM-Shoulder," "Support-TMC," and "Support-CCTV." In each worksheet, costs are broken down into infrastructure costs and incremental costs. Both infrastructure costs and incremental costs are further broken down into capital, operation and maintenance (O&M), and replacement costs. All costs described are then annualized (**Table 3.3**).

Table 3.3. Breakdown of the costs evaluated in TOPS-BC.

TOPS-BC Cost Component	Definition
Infrastructure Costs	Include the costs of equipment needed to implement ATM strategies and the labor needed for installation
Incremental Costs	The costs of one additional piece of equipment (depending on the strategy)
Capital Costs	One-time, up-front costs on capital equipment and soft costs for design, equipment installation
Operation and Maintenance (O&M) Costs	Costs for continuing operation and management of strategy until end of useful life.
Replacement Costs	Periodic costs used to replace equipment that is outdated or at the end of useful life
Annualized Costs	Amortizes capital cost over the length of time the strategy is useful and adds that cost to the operations and maintenance costs

Source: FHWA, 2017b

3.1.3 Benefits

The benefits of the Flex route were calculated through five worksheets in the TOPS-BC: "Signal Coord.", "TIM", "ATIS-DMS", "Hard Shoulder", and "Speed." Each worksheet corresponds to a strategy. The total average annual benefits of each strategy are determined based on default data and user inputs. Default data are listed as parameters in the TOPS-BC (**Table 3.1**). The values of default parameters come from national averages of observed effects and vetted parameters in other operations analysis tools. Users can overwrite defaults with locally relevant data for each strategy (FHWA, 2017b).

In worksheets "Signal Coord.," "TIM," "Hard Shoulder," and "Speed," benefits are described according to performance measures such as facility characteristics, facility performance, impacts due to strategy, travel time, ATIS time savings, travel time savings, energy and safety. Benefits in the "ATIS-DMS" worksheet are evaluated through facility performance and impacts due to strategy (**Table 3.4**).

Table 3.4. The performance measures and data used to evaluate the benefits of each strategy.

	Performance Measure	Data Used to Evaluate the Benefits of Each Strategy
How Strategy Benefits are Evaluated in the Tool	Facility Characteristics	Link Length (Miles), Total Number of Lanes, Link Capacity (All Lanes-Per Period), Free Flow Speed (MPH)
	Facility Performance	Congested Speed, Vehicle Miles Traveled (VMT), Volume to Capacity Ratio, Vehicle Hours of Travel, Incident Related Delay (hours) per Vehicle per Mile, Number of Fatality
	Impacts Due to Strategy	Change in Capacity (%), Change in Speed (%), Change in # Lanes, Reduction in Crash Rate (%), Reduction in Crash Duration (%), Reduction in Fuel Use (%), Percent Time Device is Disseminating Useful Information, Percent Drivers Using
	Travel Time	Average Person Hours of Travel Saved per Period, $ Value of Person Hour (per hour) "On-the-Clock" Auto, $ Value of Person Hour (per hour) Other Auto, $ Value of Vehicle Hour
	ATIS Time Savings	Total Hours Saved Due to ATIS Deployments
	Travel Time Savings: Non-Recurring Delay	Average Total Person Hours of Non-Recurring Delay Saved per Period, $ Value of Person Hour (per hour of Delay) "On-the-Clock" Auto, $ Value of Person Hour (per hour of Delay) Other Auto, $ Value of Vehicle Hour (per hour of Delay) Truck, Total
	Energy	Average Cost per Gallon of Fuel (Excluding Taxes), Total Fuel Savings Benefit
	Safety	$ Value of a Fatality Crash, $ Value of an Injury Crash, $ Value of Property Damage Crash, Total Modeled Crash Related
	Total Average Annual Benefits	Total Recurring Travel Time Benefit Per Period, Total Non-Recurring Related Delay Benefit Per Period, Total Fuel Savings Benefit, Total Modeled Crash Related Benefit Per Period and Number of Periods Per Year, and User Entered Benefit

	Performance Measure	Data Used to Evaluate the Benefits of Each Strategy
How Dynamic Message Sign Benefits are Evaluated in the Tool	Facility Performance	Volume Passing by the Sign Location(s) During the Period of Analysis
	Impacts Due to Strategy	Percent Time Device is Disseminating Useful Information, Percent Drivers Acting on the Information, Average Time Saved (Minutes) by Drivers Acting on the Information, Average Time
	Total Average Annual Benefits	Total Hours Saved Due to ATIS Deployments, Analysis Periods Per Year, Percent Commercial Auto, Commercial Auto Value of Time, Auto Value of Time, and User Entered Benefit

Source: MDOT, 2018; FHWA, 2017

3.1.4 Benefit-Cost Ratio Calculations

A benefit-cost ratio is calculated for each strategy in the "My Deployments" worksheet. The ratio equals annual benefits divided by annual costs. A higher ratio value indicates greater benefits relative to costs.

3.2 Method Improvements on FHWA TOPS-BC Tool

The methods adopted in the FHWA TOPS-BC tool were improved upon. Environmental impacts and other costs and benefits were included to lead to a more accurate benefit to cost ratio.

3.2.1 TOPS-BC Updates

Cost-benefit analysis best practices were compared to the current costs and benefits outlined in the TOPS-BC tool. This determined which categories should be included. The additional cost categories were added to a new section of each worksheet to evaluate the impacts of each strategy. Additional benefits were included within the "User Entered Benefit" cell at the end of each benefit worksheet.

The following impacts were added to the analysis. Providing more data on costs and benefits gives a more accurate benefit-cost ratio based on several sources (**Table 3.5**).

Table 3.5. Additional data categories included in TOPS-BC and sources of data.

Additional Data Category	Data Sources
Noise Level Effects on Wildlife	Parris and Schneider, 2008; Bee and Swanson, 2007; Halfwerk et al, 2010
Deer Related Crash Data	Forman et al, 2003; Forman and Deblinger, 2000
Housing Values Near Road	Ozdenerol, 2015; K. von Graevenitz, 2018; Szczepanska, 2015
Salt Concentration in Local Bodies of Water	Forman et al, 2003
Human Health Impacts from Living Near Road	Baudin et al, 2021
Emission Levels	Forman et al, 2003; Liu et al, 2017
Level of Biodiversity Near Road	Forman et al, 2003; Karraker et al, 2008
Habitat Fragmentation	Forman and Deblinger, 2000; Halfwerk et al, 2010

Source: Parris and Schneider, 2008; Bee and Swanson, 2007; Halfwerk et al, 2010; Forman et al, 2003; Forman and Deblinger, 2000; Ozdenerol, 2015; K. von Graevenitz, 2018; Liu et al, 2017; Consentino et al, 2014; Szczepanska, 2015; Karraker et al, 2008; Baudin et al, 2021.

The purpose of updating the FHWA TOPS-BC spreadsheet tool was to create a better understanding of the costs and benefits that should be included in the FHWA TOPS-BC tool. The current study enhances the tool to provide agencies with a more accurate evaluation of their transportation project(s).

CHAPTER 4. ANALYSIS

4.1 Comparison of Current TOPS-BC Tool and CBA Best Practices

As described in **Table 3.3**, each ATM strategy analyzed by the TOPS-BC spreadsheet is broken down into costs and benefits. Costs are broken down into basic infrastructure equipment and incremental deployment equipment. Each of those are then broken down into capital/replacement, O and M (annual) and annualized costs. **Table 4.1** illustrates the costs for each strategy.

Table 4.1. Compares the associated costs of each ATM strategy implemented on the Flex route to additional costs considered cost-benefit analysis best practices.

	TOPS-BC Associated Costs	Best Practice Costs
TMC Hardware for Information Dissemination	✓	✓
TMC Software for Information Dissemination	✓	✓
TMC System Integration	✓	✓
Communication Line	✓	✓
Variable Message Sign	✓	✓
Variable Message Sign Tower	✓	✓
Linked Signal System LAN	✓	✓
Signal Controller	✓	✓
Communication Line	✓	✓
Loop Detectors (2)	✓	✓
TMC Hardware for Signal Control	✓	✓
TMC Software/System Integration	✓	✓
Labor	✓	✓
Signal Preemption Receiver	✓	✓
Signal Controller Update	✓	✓
Telecommunication (low usage)	✓	✓
Signal Preemption Processor	✓	✓
Cell based Communications Equipment	✓	✓
Video Monitors/Wall for Incident Detection	✓	✓
TMC Incident Response Hardware	✓	✓
TMC System Integration	✓	✓
TMC Labor	✓	✓
Emergency Management Center Hardware	✓	✓
Emergency Response Labor	✓	✓
Incident Response Vehicle (per FSP vehicle)	✓	✓
Incident Response Labor (per FSP vehicle)	✓	✓
Communication Line (per FSP vehicle)	✓	✓
TMC Lane Control Hardware	✓	✓
TMC Lane Control Software	✓	✓
Speed Signal Controller	✓	✓
Communications	✓	✓
Traffic Management Center	✓	✓

Table 4.1 (cont'd)

Hardware/software for Traffic Surveillance	✓	✓
System Integration	✓	✓
Video Camera	✓	✓
Camera Tower	✓	✓
Deer Related Crashes		✓
Increase in Invasive Species		✓
Decrease in Egg Mass Density and Embryo Survival of Salamanders and Frogs		✓
Increase in Water Pollution		✓
Decrease in Bird Eggs and Fledglings Near Road		✓
Noise Level Impacts on Wildlife, Human Health and Day to Day Life		✓
Increase in Emissions		✓
Excess Salt Usage		✓
Habitat Fragmentation		✓
Decrease in Housing Values Within a Certain Distance from Road		✓

Source: MDOT, 2018; MDOT, 2013; Karraker et al, 2008; Consentino et al, 2014; Rhodes et al, 2014; Huijser et al, 2009; Mack, 2019; Hadi et al, 2008; Reponen et al, 2003

Table 4.2 lists the benefits of each strategy implemented on the Flex route.

Table 4.2. Compares the associated benefits of each ATM strategy implemented on the Flex route to additional benefits considered cost-benefit analysis best practices.

	TOPS-BC Associated Benefits	Best Practice Benefits
Link Capacity (All Lanes per Period)	✓	✓
Free Flow Speed (MPH)	✓	✓
Link Volume (during period of analysis)	✓	✓
Congested Speed	✓	✓
Vehicle Miles Traveled	✓	✓
Volume to Capacity Ratio	✓	✓
Vehicle Hours of Travel	✓	✓
Incident Related Delay per Vehicle per Mile	✓	✓
Number of Fatality Crashes	✓	✓
Number of Injury Crashes	✓	✓
Number of Property Damage Only Crashes	✓	✓
Fuel Consumption (Gallons)	✓	✓
Change in Capacity (%)	✓	✓
Change in Speed (%)	✓	✓
Change in # of Lanes	✓	✓
Reduction in Crash Rate (%)	✓	✓
Reduction in Fuel Use (%)	✓	✓
Average Person Hours of Travel Saved per Period	✓	✓
$ Value of Person Hour (per hour) "On-the-Clock" Auto	✓	✓
$ Value of Person Hour (per hour of Delay) Other Auto	✓	✓
$ Value of Vehicle Hour (per hour of Delay) Truck	✓	✓
Total Non-Recurring Delay Benefit per Period	✓	✓
Average Cost per Gallon of Fuel (excluding taxes)	✓	✓
Total Fuel Savings Benefit	✓	✓
$ Value of Fatality Crash	✓	✓
$ Value of Injury Crash	✓	✓
$ Value of a Property Damage Crash	✓	✓
Percent Time Device is Disseminating Useful Information	✓	✓

Table 4.2 (cont'd)

Percent Drivers Acting on the Information	✓	✓
Average Time Saved (Minutes) by Drivers Not Acting on Information	✓	✓
Total Hours Saved due to ATIS developments	✓	✓
Decrease in Deer Related Crashes		✓
Reduction in Ambient Noise Levels on Wildlife		✓
Decrease in Emissions		✓
Decrease in Salt Concentration in Nearby Bodies of Water		✓
Decrease in Number of Invasive Species		✓
Increase in Egg Mass Density and Embryo Survival of Salamanders and Frogs		✓
Decrease in Water Pollution		✓
Increase in Bird Eggs and Fledglings near Road		✓
Increase in Housing Values Within a Certain Distance from Road		✓
Reduction in Human Health Effects from Noise Levels		✓

Source: MDOT, 2018; MDOT, 2013; Karraker et al, 2008; Consentino et al, 2014; Rhodes et al, 2014; Huijser et al, 2009; Mack, 2019; Hadi et al, 2008; Reponen et al, 2003

Two distinct categories of local costs and benefits are missing from the TOPS-BC analysis. The additional cost categories of road projects like the US-23 Flex route are road ecology and housing values. These additional cost and benefit categories relate back to cost-benefit analysis best practices (Boardman et al, 2017).

CHAPTER 5: DISCUSSION

The thesis outlines the gaps in the FHWA TOPS-BC tool based on cost-benefit analysis best practices. The results suggest additions are needed to version 1.0 of the tool. The thesis compares the costs and benefits listed in the TOPS-BC spreadsheet tool and contrasts costs and benefits to best practices found in the literature. From the comparison, two missing categories were found. The most important cost category missing were environmental impacts, otherwise known as road ecology (Forman et al, 2003). The category is significant because of the many ways the local ecosystem can be impacted. Another category missing is the decreased value of houses close to a road. Cost-benefit analysis research articles seem to mostly study the effects of ATM projects on safety and operation aspects of the road (Guerriari and Mauro, 2016; Geistefeldt, 2012; Kononov et al, 2012). My research used cost benefit analysis best practices to ensure the FHWA TOPS-BC tool is as accurate as possible. The tool aspires to consider all costs and benefits when evaluating road projects.

Road ecology impacts are the most significant aspect missing from version 1.0 of the TOPS-BC tool (Boardman et al, 2017). The category is the most important because it highlights the many ways roads and road projects like the US-23 Flex route impact the local ecosystem. The local ecology surrounding US-23 is such that it may be affected by a road project such as the US-23 Flex Route. For example, there are several bodies of water nearby that may be harmed by water pollution from chemicals in the added exhaust fumes and through construction of the Flex Route (Forman et al, 2003). More cars on US-23 mean more fumes, even if the cars are moving faster. The larger bodies of water are Whitmore, Wildwood, and Horseshoe Lakes. There are smaller lakes dotted near the road, but these do not have names (Google Maps, 2021). The major and minor bodies of water could also be harmed by excess road salt used on the roads. Yellow spotted salamander and wood frog egg mass density and embryo survival were affected by the concentration of road salt in the Adirondacks (Karraker et al, 2008). Although there are not yellow spotted salamanders in Michigan, a species of the same genus, called the blue spotted salamander, is common throughout the state (Tekiela, 2004a). Wood frogs are also common. These species may be present in the Northfield Woods Preserve, a protected area along the Flex. Both species' egg mass density and embryo survival may be affected by the possible excess of road salt in nearby bodies of water. More salt could be put down on the road because of the usage of the shoulder for the Flex route. As a result, the biodiversity of the local ecosystem could be affected (Karraker et al, 2008; Halfwerk et al, 2010). The blue spotted salamander and wood frog reproductive cycle may be interrupted by excess salt usage (Karraker et al, 2008).

Folke et al (2004) (as cited in Balmford et al, 2011) found the resiliency of natural systems decreases with a lack of biodiversity. Invasive species can invade native plant habitat with the help of humans. They can be planted along roadsides through construction projects like the US-23 Flex Route (Forman et al, 2003; Forman & Deblinger, 2000). These invasive plant species could impact the number of native species along the edges of US-23, reducing native biodiversity. Local animals could also suffer from noise levels (Forman et al, 2003; Halfwerk et al, 2010). In turn, they could benefit from the reduced levels of noise due to the Flex. Halfwerk et al (2010) studied the impact of highway noise levels on a bird species called Parus major or the Great Tit. They found noise levels in April to have a negative effect on the number of eggs and fledglings in each nest. Although this bird species is uncommon in Michigan, there are other bird species that may be affected (Tekiela, 2004b). Additionally, birds in the area could have their songs impacted by the noise levels along the Flex (Parris and Schneider, 2009). Parris and

Schneider (2009) explained that potential mates cannot hear each other because of high levels of road noise. Birds could directly benefit if the noise level from the Flex was reduced.

A deer is another animal that could be affected and aided by reduced levels of congestion on the Flex Route. Around the Northfield Woods Preserve, more deer could be crossing the busy highway, leading to more deer-related crashes. In 2018, Michigan experienced an increase in deer related crashes due to increases in the herd (Mack, 2019). In Livingston and Washtenaw Counties, which the US-23 Flex route runs through, about 17% and 9% of total crashes involved deer, respectively (Mack, 2019). Although neither are high percentages, this environmental impact is still worth considering as a possible cost of not implementing a transportation project like the US-23 Flex route. Rhodes et al (2014) found increasing capacity on an existing road, like in the US-23 Flex route project, reduces the mortality rate of mammals crossing it. Adding a new road conversely increases the mortality rate. Thus, adding capacity on US-23 may lower the number of deer-related crashes.

Including these environmental impact categories are important because the only environmental impacts addressed in version one of the tool were noise impacts and level of emissions. No specification existed on how the noises and emissions would impact local wildlife or humans. My study is different because I determined what is missing from the TOPS-BC tool based on cost benefit analysis best practices. The results do not focus on any one category of costs and benefits. By allowing more cars to travel on the US-23 Flex route, biodiversity, air quality, noise levels and the overall health of the local ecosystem may be affected. A study by Wainaina et al. (2020) compiled current CBA research regarding economic analysis of landscape restoration. Although not directly relevant to transportation projects, the study demonstrated that environmental impacts can be monetized. Since environmental impacts can be monetized, the impacts I mention can be placed in the TOPS-BC tool and can be used to evaluate projects, such as the US-23 Flex route. Adding these new costs and benefits creates a more complete picture of the impacts of road projects like the US-23 Flex route.

Housing values should also be included in a cost-benefit analysis of transportation projects. Negative impacts from high levels of noise near the Flex include human health impacts. Thus, the health of the people living within 200 meters of the Flex route may be impacted by the high levels of noise. There are over 200 houses, one apartment complex and one mobile home estate. Most of the houses are north of 6 Mile, near Whitmore Lake (Google Maps, 2021). That particular distance, 200 meters, was chosen because of the findings of K. von Graevenitz, 2018. What this indicates is that those houses may have noise level issues with the US-23 Flex route. K. von Graevenitz (2018) found that noise levels above 55 dB, the typical urban level, are felt by houses within 200 meters of a large road. Another relevant study is from Szczepanska et al, 2015. The researchers used the noise sensitivity depreciation index to analyze the noise levels near two apartment estates in Poland. They found that the lowest housing prices were the closest to the road in both estates but the Sródmiescie apartments were exposed to higher noise levels because of being on a national transit road. Although not the same type of road as the Flex route, both areas may experience similar effects from noise levels. What this means is that housing prices of houses and apartments within 200 meters of the Flex route may be lower compared to houses a mile away. Although the cost of the house may be lower than others further away, the people living there will have a lower quality of life because of the noise (Nelson, 2008). The Flex route, by reducing the levels of noise, may increase the value of some of these houses. My research supported my hypothesis that houses near a congested, noisy road have lower prices relative to ones further away. People are willing to pay less for a house or apartment if there are high levels of noise because the environment will have a negative impact on their quality of life. An important consideration is to ensure the impacts of noise are not from the road itself when analyzing the US-23 Flex route. Another question is whether there is a significant marginal effect of an active traffic management strategy like the Flex route on people's willingness to pay. A study has not answered that question specifically for ATM strategies.

Including the above categories ensures the cost benefit analysis is more complete than in version one of the TOPS-BC tool. The inclusion removes the politics of cost-benefit analysis. For decades, politics have influenced the practice (Revesz and Livermore, 2008). Impacts of road projects on the environment should be considered. Roads have a variety of negative impacts on the local environment. In a time of overharvesting and degradation of the natural ecosystem, road ecology should not be ignored (Balmford et al, 2011). As Boardman et al (2017) describes, not all costs and benefits will be analyzed every time. My results point to the relevant categories attributed to the US-23 Flex route while also ensuring the inclusion of nearly all real costs and benefit categories. This way politics can be removed (Revesz and Livermore, 2008) and a more accurate benefit to cost ratio can be found.

One important limitation is that evidence of certain environmental costs and benefits are ambiguous, like the effect of chlorinated organic compounds on the local ecosystem (Boardman et al, 2017). A road project like the US-23 Flex route will impact some areas of the local ecosystem but not in others (Boardman et al, 2017). However, all categories should still be included. Another limitation is that some costs and benefits are at risk of being double-counted (Balmford et al, 2011; Navrud et al, 2002). As a result, benefits would be overestimated (Navrud et al, 2002). Balmford et al (2011) explained that it is best to use "separate end-benefits provided by ecosystem services" (Balmford et al, 2011, 165). End-benefits are what can be gained from beneficial ecosystem processes such as pollination and air quality regulation (Balmford et al, 2011). A third limitation is that the analysis is based on version 1.0 of the FHWA TOPS-BC tool. The results of this analysis are not changed because road ecology, other than emissions and noise impacts, is not included in version four of the tool.

The implication of this research is that future transportation projects will be analyzed more accurately using the FHWA TOPS-BC tool. The benefit to cost ratio will be different than if all benefits and costs were not included, making the analysis tool more effective. There is greater likelihood that the decision to conduct traffic work will be decided based on the ecological and human impacts rather than awarding contracts as political favors. This will increase the chance that politics can be removed from the analysis of road projects like the Flex route (Revesz and Livermore, 2008; Boardman et al, 2017). The study provides a summary of other costs and benefits not typically analyzed in transportation CBA studies. The findings also helped fill research gaps because costs and benefits were included from CBA best practices. Costs and benefits are in one place, so a search of the literature is not needed to evaluate their relevance. A quantitative study is necessary to provide evidence that the new costs and benefits apply to certain transportation projects like the Flex route.

CHAPTER 6: CONCLUSION

To make the FHWA TOPS-BC cost-benefit analysis tool complete, additional cost and benefit categories should be included. The two categories are road ecology impacts and housing values. The most important category missing was road ecology.

Several limitations exist in my study. One, I based my findings on the sources I found. The search was not exhaustive, so most likely some sources are missing. However, the additional sources would not have changed the result that road ecology was the most important category. A plethora of environmental impacts exist from any road project. Two, the study is qualitative. I was not able to confirm with absolute certainty whether each individual category would be impacted by the US-23 Flex route. A quantitative study is needed to provide specific evidence. All other evidence is related to transportation projects in general. My study provides a different perspective than one that focused solely on financial costs. A third limitation is that my study changed from quantitative to qualitative halfway through the research process due to COVID-19 and the unavailability of data.

I suggest the next step in this research process should be to do a quantitative study. The focus of the study should be on road ecology impacts from an ATM perspective. There are not enough studies about road ecology impacts of transportation projects employing the hard shoulder running strategy. Each ATM strategy is different, meaning they may all impact the environment differently. I would also suggest the new costs and benefits be added to the tool. Updating the FHWA TOPS-BC tool will help to analyze future Flex routes and other transportation projects. These additions may have far-reaching impacts for other transportation projects across the United States.

APPENDICES

APPENDIX A.

Terminologies

Dynamic Message Sign	"Gives advance notice of corridor traffic conditions and real time traffic speeds are displayed as recommended speeds" (Michigan Department of Transportation, 2017, 4).
Highway Advisory Radio	Provides alternative routes to commuters so congestion is avoided (Bagloee et al, 2014).
Pre-Trip Traveler Information	Information for commuters on the news which outlines the location of traffic incidents and congestion (Robinson, 2018).
Traffic Signal Coordination Systems	Multiple intersections are coordinated to make it easier for cars to travel in a certain direction (FHWA, 2017b).
Traffic Signal Coordination Systems: Pre-set Timing	"Traffic signal timing, phase plan and phase times are predetermined" (FHWA, 2017e, 4).
Traffic Signal Coordination Systems: Traffic Actuated	"Detector actuations partially control the traffic signals" (FHWA, 2017e, 2).
Traffic Signal Coordination Systems: Central Control	Refers to the Traffic Management Center control of the remote control unit at the local intersection (FHWA, 2005).
Traffic Signal Coordination Systems: Transit Signal Priority	"An operational strategy that is applied to reduce the delay transit vehicles experience at traffic signals." (FHWA, 2017e, 6).
Ramp Metering Systems	Traffic signals used to control how many vehicles enter the freeway from an on-ramp. The strategy breaks up groups of cars and trucks (FHWA, 2017d).
Ramp Metering Systems: Central Control	Central computer program used to control ramp metering systems (FHWA, n.d.).
Ramp Metering Systems: Traffic Actuated	Meters change based on current traffic conditions (FHWA, 2017d).
Ramp Metering Systems: Preset Timing	Meters are programmed based on historical trends in congestion (FHWA, 2017d).

Traffic Incident Management	Reduces impacts of incidents and crashes by removing the obstructions quickly and safely (FHWA, 2020c).
ATDM Speed Harmonization	When speed limits change in response to weather or congestion (Hadiuzzaman and Qiu, 2013).
ATDM Hard Shoulder Running	Use of the shoulder to alleviate congestion during peak traffic times (Guerriari & Mauro, 2016).
Road Weather Management	En-route traffic advisories providing warnings to travelers; controls traffic during inclement weather (FHWA, 2020b).
Work Zone	"Predicts travel time, delay or speed in a freeway work zone, on a real-time basis" (Pant, n.d, 1).
Employer Based Traveler Demand Management	Program implemented by employers to reduce the number of people driving to and from work (Ko & Kim, 2017).
ATDM High Occupancy Toll Lanes	A priced lane which makes people not meeting the minimum passenger requirements pay a fee (US Department of Transportation, 2020a).
Supporting Strategies: Traffic Management Center	The buildings where traffic information is processed and disseminated to the public (those driving, the media, etc.) (US Department of Transportation, 2020b).
Supporting Strategies: Loop Detection	Located in the ground, it detects vehicles that pass over (US Department of Transportation, 2006).
Supporting Strategies: Closed Circuit Television (CCTV)	Identify location of incidents, traffic conditions, weather issues, etc along the highway (FHWA, 2016b).

APPENDIX B.

Acronyms

ATM	Active Traffic Management
FHWA	Federal Highway Administration
TSM&O	Transportation Systems Management and Operations

REFERENCES

REFERENCES

Abo-Qudais, S. and Abu-Qdais. 2005. "Perceptions and attitudes of individuals exposed to traffic noise in working places." *Building and Environment* 40: 778-787.

Asif Khan, M., Ahmed, A., Irshad Ul Haq Kayani, W. 2017. "Optimal timing for lane(s) addition to an existing highway: a benefit-cost approach."*Arabian Journal for Science and Engineering* 44: 4169-4182.

Bagloee, S.A., Ceder, A., Bozic, C. 2012. "Effectiveness of en route traffic information in developing countries using conventional discrete choice and neural-network models." *Journal of Advanced Transportation* 48 (6): 486-506.

Balmford, A., Fisher, B., Green, R.E., Naidoo, R., Strassburg, B., Kerry Turner, R., Rodrigues, A.S.L. 2011. "Bringing ecosystem services into the real world: an operational framework for assessing the economic consequences of losing wild nature." *Environmental Resource Economics* 48: 161-175.

Barth, M. and Boriboonsomsin, K. 2008. "Real-world carbon dioxide impacts of traffic congestion." *Transportation Research Record: Journal of the Transportation Research Board, No. 2058* 163-171.

Baudin, C., Lefevre, M., Champelovier, P., Lambert, J., Laumon, B., Evrard, A. 2021. "Self rated health status in relation to aircraft noise exposure, noise annoyance or noise sensitivity: the results of a cross-sectional study in France." *BMC Public Health* 21.

Bee, M.A. and Swanson, E.M. 2007. "Auditory masking of anuran advertisement calls by road traffic noise." *Animal Behavior* 74(6): 1765-1776.

Birch, J.C., Newton, A.C., Alvarez, C.A., Cantarello, E., Echeverria, C., Kitzberger, T., Schiappacasse, I., Tejedor, Garavito, N.T. 2010. "Cost-effectiveness of dryland forest Restoration evaluated by spatial analysis of ecosystem services." *PNAS* 107 (50): 21925-21930.

Boardman, A.E., Greenberg, D.H., Vining, A.R., Weimer, D.L. (2017). Cost-benefit analysis: concepts and practice. Cambridge: Cambridge University Press.

Brinckerhoff, P. 2010. "Synthesis of Active Traffic Management experiences in Europe and the United States." Publication # FHWA-HOP-10-031. March 2010.

Chun, P. & Fontaine, M. (2016). *Evaluation of the I-66 Active Traffic Management System* (VTRC 17-R5). Retrieved from https://rosap.ntl.bts.gov/view/dot/31333.

Coffin, A.W. 2007. “From roadkill to road ecology: A review of the ecological effects of roads.” *Journal of Transport Geography* 15: 396-406.

Consentino, B.J., Marsh, D.M., Jones, K.S., Apodaca, J.J., Bates, C., Beach, J., Beard, K.H., Becklin, K., Bell, J.M., Crockett, C., Fawson, G., Fjelsted, J., Forys, E.A., Genet, K.S., Grover, M., Holmes, J., Indeck, K., Karraker, N.E., Wiley, A. 2014. “Citizen science Reveals widespread negative effects of roads on amphibian distributions.” *Biological Conservation* 180: 31-38.

Daniels, S., Martensen, H., Schoeters, A., Van den Berghe, W., Papadimitriou, E., Ziakopoulos, A., Kaiser, S., Aigner-Breuss, E., Soteropoulos, A., Wijnen, W., Weijermars, W., Carnis, L., Elvik, R., Martin Perez, O. 2019. “A systematic cost-benefit analysis of 29 road safety measures.” *Accident Analysis and Prevention* 133: 105292.

Evans, A. (2001). *Report of the Hundred and Seventeenth Round Table on Transport Economics: Economic Evaluation of Road Traffic Safety Measures.* Retrieved from https://www.yumpu.com/en/document/read/3806695/ecmt-round-tables-economic-evaluation-of-road-traffic-safety-.

Farrag, S.G., Outay, F., Yasar, A.U., El-Hansali, M.Y. 2020. “Evaluating active traffic Management strategies under non-recurring congestion: simulation-based with benefit cost analysis case study.” *Sustainability* 12: 1-15.

Federal Highway Administration. 2005. “Traffic Control Systems Handbook: Chapter 8. System Control.” FHWA-HOP-06-006.

Federal Highway Administration. 2012. “Operations Benefit/Cost Analysis Desk Reference” Publication FHWA-HOP-12-028.

Federal Highway Administration. 2012b. “ATDM Program Brief: Active Traffic Management.” Publication FHWA-HOP-13-003.

Federal Highway Administration. 2016. “Benefit Cost Analysis Transportation Systems Management and Operations.” FHWA-HOP-16-006.

Federal Highway Administration. 2016b. “Transportation Management Center Video Recording and Archiving Best General Practices.” FHWA-HOP-16-033.

Federal Highway Administration. 2017b. “Operations Benefit/Cost Analysis TOPS-BC User's Manual – Providing Guidance to Practitioners in the Analysis of Benefits and Costs of Management and Operations Projects.”

Federal Highway Administration. 2017c. “Transportation Systems Management and Operations Benefit-Cost Analysis Compendium.” Publication #FHWA-HOP-14-032.

Federal Highway Administration. 2017d. "Ramp Metering: A Proven, Cost Effective Operational Strategy-A Primer."

Federal Highway Administration. 2017e. "Traffic Signal Timing Manual." Chapter 5 and Chapter 9. Retrieved from: https://ops.fhwa.dot.gov/publications/fhwahop08024/chapter5.htm

Federal Highway Administration. 2018. "Highway Safety Benefit-Cost Analysis Guide." FHWA-SA-18-001.

Federal Highway Administration. 2020. TOPS-BC V 1.0. Retrieved from: http://www.ops.fhwa.dot.gov/publications/fhwahop12028/

Federal Highway Administration, 2020b. "Weather Responsive Management Strategies." Federal Highway Administration. https://www.fhwa.dot.gov/innovation/everydaycounts/edc_5/weather_strategies.cfm

Federal Highway Administration. 2020c. "Traffic Incident Management." Federal Highway Administration. Retrieved from: https://ops.fhwa.dot.gov/eto_tim_pse/about/tim.htm

Federal Highway Administration. 2020d. "Active Traffic Management Implementation and Operations Guide." U.S. Department of Transportation Federal Highway Administration. Retrieved from: https://ops.fhwa.dot.gov/publications/fhwahop17056/chap1.htm#12b

Federal Highway Administration. (2020f, February 28). *What is Transportation Systems Management and Operations (TSMO)?* Organizing and Planning for Operations. Retrieved from: https://ops.fhwa.dot.gov/tsmo/#q1.

Federal Highway Administration, 2020g. "Active Traffic Management (ATM) Implementation and Operations Guide." https://ops.fhwa.dot.gov/publications/fhwahop17056/chap1.htm#12a

Federal Highway Administration, n.d. 'Ramp metering strategies.' *Ramp Management and Control Handbook.* https://ops.fhwa.dot.gov/publications/ramp_mgmt_handbook/manual/manual/5_1.htm

Forman, R.T.T., and Deblinger, R.D. 2000. "The ecological road-effect zone of a Massachusetts (U.S.A.) Suburban Highway." *Conservation Biology* 14(1): 36-46.

Forman, R.T.T., Sperling, D., Bissonette, J.A., Clevenger, A.P., Cutshall, C.D., Dale, V.H., Fahrig, L., France, R., Goldman, C.R., Heanue, K., Jones, J.A., Swanson, F.J., Turrentine, T., Winter, T.C. (2003). *Road Ecology: Science and Solutions* Island Press.

Frank, A. (2017, November 15). *Michigan opens 'flex route' on U.S. 23 to ease traffic congestion.* Crain's Detroit Business. https://www.crainsdetroit.com/article/20171115/news01/645071/michigan-opens-flex-route-on-us-23-to-ease-traffic-congestion

Geistefeldt, J. 2012. "Operational experience with temporary hard shoulder running in Germany." *Transportation Research Record: Journal of the Transportation Research Board* No. 2278: 67-73.

Google (n.d.) [Michigan U.S. 23]. Retrieved February 13, 2021, from US-23 - Google Maps.

von Graevenitz, K. 2018. "The amenity cost of road noise." *Journal of Environmental Economics and Management* 90: 1-22.

Guerrieri, M., Mauro, R. 2016. "Capacity and safety analysis of hard-shoulder running (HSR): a motorway case study." *Transportation Research Part A* 92: 162-183.

Hadi, M., Shen, L., Zhan, C., Xiao, Y., Corbin, S., Chen, D. 2008. "Operation data for evaluating benefits and costs of Advanced Traffic Management components." *Transportation Research Record: Journal of the Transportation Research Board* No. 2086: 48-55.

Hadiuzzaman, M.D., and Qiu, T.Z. 2013. "Cell transmission model based variable speed limit control for freeways." *Canadian Journal of Civil Engineering* 40: 46-56.

Halfwerk, W., Holleman, L.J.M., Lessells, C.M., Slabbekoom, H. 2011. "Negative impact of traffic noise on avian reproductive success." *Journal of Applied Ecology* 48: 210-219.

Harrison, M. (2010). "Valuing the future: the social discount rate in cost-benefit analysis." *Australian Government Productivity Commission.* https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1599963

Hennessy, D.A., Wiesenthal, D.L., Kohn, P.M. 2000. "The influence of traffic congestion, daily hassles, and trait stress susceptibility on state driver stress: an interactive perspective." *Journal of Applied Biobehavioral Research* 5(2): 162-179.

Hofstetter, P. and Muller-Wenk, R. 2005. "Monetization of health damages from road noise with implications for monetizing health impacts in life cycle assessment." *Journal of Cleaner Production* 13 (13-14): 1235-1245.

Hussen, A. (2013). *Principles of Environmental Economics and Sustainability.* New York, NY: Routledge.

Karraker, N. E., Gibbs, J.P., Vonesh, J.R. (2008). "Impacts of road deicing salt on the demography of vernal pool-breeding amphibians." *Ecological Applications: Ecological Society of America* 18(3): 724-734.

Kary, B. (n.d.) *Active Traffic Management in Minnesota* [PowerPoint slides]. Communications Update the Minnesota Department of Transportation (codot.gov)

Kassens-Noor, E., Savolainen, P.T., Gates, T. (2019). Performance and Safety of the US-23 Flex Route (OR19-114): Research Advisory Panel (RAP) Meeting [PowerPoint slides].

Kassens-Noor, E., Savolainen, P.T., Gates, T. (2020). Performance and Safety of the US-23 Flex Route (OR19-114): Research Advisory Panel (RAP) Meeting [PowerPoint slides].

Kolosz, B. and Grant-Muller, S. 2015. "Extending cost-benefit analysis for the sustainability impact of inter-urban Intelligent Transport Systems." *Environmental Impact Assessment Review* 50: 167-177.

Kononov, J., Hersey, S., Reeves, D. 2012. "Relationship between freeway flow parameters and safety and its implications for hard shoulder running." *Transportation Research Record: Journal of the Transportation Research Board* 2280.

Levecq, C., Kuhn, B., Jasek, D. (2011). "Best practices and outreach for Active Traffic Management Final Report." University Transportation Center for Mobility. DOT Grant No. DTRT06-G-0044.

Litman, T. 2009. "Transportation Cost and Benefit Analysis: Techniques, Estimates and Implications." *Victoria Transport Policy Institute* Retrieved from: https://eclass.upatras.gr/modules/document/file.php/CIV1532/2.8%20Transportation%20Cost%20and%20Benefit%20Analysis.pdf

Logar, I., Brouwer, R., Paillex, A. 2019. "Do the societal benefits of river restoration outweigh their costs? A cost-benefit analysis." *Journal of Environmental Management* 232: 1075 -1085.

Liu, Y., Liao, W., Li, L., Huang, Y., Xu, W. "Reduction measures for air pollutants and greenhouse gas in the transportation sector: A cost benefit analysis." *Journal of Cleaner Production* 207: 1023=1032.

Ma, J., Hu, J., Hale, D.K., Bared, J. 2016. "Dynamic hard shoulder running for traffic incident management." *Transportation Research Record: Journal of the Transportation Research Board* No. 2554: 120-128.

Mack, J. (2019, October 15). *See number of 2018 deer crashes in your Michigan county, city or township.* Mlive. https://www.mlive.com/news/g66I-2019/10/fa953518fe5490/see-number-of-deer-crashes-in-your-michigan-county

Michigan Department of Transportation. 2018. TOPS-BC V 1.0. Retrieved from: http://www.ops.fhwa.dot.gov/publications/fhwahop12028/.

Michigan Department of Transportation. (2016, September 30). *Inside MDOT: Flex Route* [Video]. https://www.youtube.com/watch?list=PLnw95w_o1ozYnCT-JiwfkhEhTI9JGuw-O&time_continue=138&v=WF0IH9d7H_k&feature=emb_logo

Michigan Department of Transportation. (2017, August 11) *Driving the Flex Route* [Video]. YouTube. https://www.youtube.com/watch?v=6lrVV73FDVo

Michigan Department of Transportation. 2018. TOPS-BC V 1.0. Retrieved from: http://www.ops.fhwa.dot.gov/publications/fhwahop12028/

Michigan Department of Transportation. 2020. "US-23 Flex Route." Retrieved from https://www.michigan.gov/mdot/0,4616,7-151-9621_11008_78923---,00.html

Minnesota Department of Transportation, 2020b. "MnPASS: How It Works." Retrieved from https://www.dot.state.mn.us/mnpass/howmnpassworks.html.

Mirshahi, M., Obenberger, J., Fuhs, J., Howard, C.E., Krammes, R.A., Kuhn, B.T., Mayhew, R.M., Moore, M.A., Sahebjam, K., Stone, C.J., Yung, J.L. 2007. "Active Traffic Management: The Next Step in Congestion Management." Publication # FHWA-PL-07-012.

Murphy, C.B. "Present Value-PV." *Investopedia.* Retrieved from: https://www.investopedia.com/terms/p/presentvalue.asp

Naess, P. 2006. "Cost-benefit analyses of transportation investments: neither critical nor realistic." *Journal of Critical Realism* 5(1): 32-60.

Navrud, S. (2002). "The state-of-the-art on economic valuation of noise." *Final Report to European Commission DG Environment*. Retrieved from *The State-of-the-art on economic valuation of Noise (researchgate.net)

Nelson, J.P. (2008). Hedonic property value studies of transportation noise: aircraft and road Traffic. In Baranzini, A., Ramirez, J., Schaerer, C., Thalmann, P. (Eds.*) Hedonic Methods in Housing Markets* (pp. 57-82). Springer.

Newton, A.C., Hodder, K., Cantarello, E., Perrella, L., Birch, J.C., Robins, J., Douglas, S., Moody, C., Cordingley, J. 2012. "Cost-benefit analysis of ecological networks assessed through spatial analysis of ecosystem services." *Journal of Applied Ecology* 49: 571-580.

Odeck, J. and Kjerkreit, A. 2019. "The accuracy of benefit-cost analyses (BCAs) in transportation: An ex-post evaluation of road projects." *Transportation Research Part A: Policy and Practice* 120: 277-294.

Ozdenerol, E., Huang, Y., Javadnejad, F., Antipova, A. 2015. "The impact of traffic noise on housing values." Journal *of Real Estate Practice and Education* 18 (1): 35-54.

Palmer, S. (2017). Dynamic Shoulder Use in Michigan [PowerPoint Slides]. Retrieved from: https://www.dot.state.oh.us/MAASTO2017/Pages/Presentations.aspx?View=%7B34b689aa-6171-49cd-9c04-c835e7937bc5%7D&SortField=Title&SortDir=Desc

Pant, P.D. n.d. *Smart Work Zone Systems.* Federal Highway Administration. Retrieved from: https://ops.fhwa.dot.gov/wz/workshops/accessible/Pant_paper.htm

Parris, K.M. and Schneider, A. 2009. "Impacts of traffic noise and traffic volume on birds of roadside habitats." *Ecology and Society* 14(1): 1-23.

Poulopoulou, M. and Spyropoulou, J. 2019. "Active traffic management in urban areas: Is it effective for professional drivers? The case of variable message signs." *Transportation Research Part A: Policy and Practice* 130: 412-423.

Reniers, G., Talarico, L., Paltrinieri, N. (2016). "Chapter 16. Cost-Benefit Analysis of Safety Measures." *Dynamic Risk Analysis in the Chemical and Petroleum Industry* 195-205.

Reponen, T., Grinshpun, S.A., Trakumas, S., Martuzevicius, D., Wang, Z., LeMasters, G., Lockey, J.E., Biswas, P. 2003. "Concentration gradient patterns of aerosol particles near interstate highways in the Greater Cincinnati airshed." *Journal of Environmental Monitoring* 5: 557-562.

Revesz, R.L. and Livermore, M.A. (2008). *Retaking Rationality: How Cost-Benefit Analysis Can Better Protect the Environment and Our Health.* Oxford, NY: Oxford University Press, Inc.

Rhodes, J.R., Lunney, D., Callaghan, J., McAlpine, C.A. 2014. "A few large roads or many small ones? How to accommodate growth in vehicle numbers to minimize impacts on wildlife." *PLOS ONE*.

Robinson, E. 2018. "State of the Practice for Traveler Information Systems." Publication HRT-17-014.

Rouquette, J.R., Posthumus, H., Gowing, D.J.G. Gowing, Tucker, G., Dawson, Q.L., Hess, T.M., Morris, J. 2009. "Valuing nature-conservation interests on agricultural floodplains." *Journal of Applied Ecology* 46: 289-296.

Rowden, P., Matthews, G., Watson, B., Biggs, H. 2011. "The relative impact of work-related stress, life stress and driving environment stress on driving outcomes." *Accident Analysis and Prevention* 43: 1332-1340.

Self, P. (1975). *Econocrats and the policy process: the politics and philosophy of cost benefit analysis.* Retrieved from: https://books.google.com/books?hl=en&lr=&id=flBdDwAAQBAJ&oi=fnd&pg=PP8&dq=cost+benefit+analysis+roads&ots=jGO5dD7BHo&sig=g0acn-6C5TA5NSYnQBazGy6CRpc#v=onepage&q=cost%20benefit%20analysis%20roads&f=false

Seppelt, R., Dormann, C.F., Eppink, F.V., Lautenbach, S., Schmidt, S. 2011. 2011. "A quantitative review of ecosystem service studies: approaches, shortcomings and the road ahead." *Journal of Applied Ecology* 48: 630-636.

Sisiopiku, V. 2012. Active Traffic Management as a Tool for Addressing Traffic Congestion, Intelligent Transportation Systems, Dr. Ahmed Abdel-Rahim (Ed.), ISBN: 978-953-51-0347-9, InTech, Available from: http://www.intechopen.com/books/intelligent-transportation-systems/active-traffic-management-as-a-tool-for- addressing-traffic-congestion-

Smart, R.G., Stoduto, G., Mann, R.E., Adlaf, E.M. 2004. "Road rage experience and behavior: vehicle, exposure, and driver factors." *Traffic Injury Prevention* 5: 343-348.

Soriguera, F. 2014. "On the value of highway travel time information systems." *Transportation Research Part A: Policy and Practice* 70: 294-310.

Soriguera, F., Torne, J.M., Rosas, D. 2013. "Assessment of dynamic speed limit management on metropolitan freeways." *Journal of Intelligent Transportation Systems* 17(1): 78-90.

Szczepanska, A., Senetra, A., Wasilewicz-Pszczolkowska, M. 2015. "The effect of road traffic noise on the prices of residential property-A case study of the polish city of Olsztyn." *Transportation Research Part D* 36: 167-177.

Tekiela, S. (2004a). *Reptiles and Amphibians of Michigan Field Guide.* Adventure Publications.

Tekiela, S. (2004b). *Birds of Michigan.* Adventure Publications.

U.S. Department of Transportation. (2006). "Chapter 1, Traffic Detector Handbook: Third Edition-Volume I." Publication #FHWA-HRT-06-108.

U.S. Department of Transportation. (2015). *Transportation Systems Management and Operations Benefit-Cost Analysis Compendium.* Publication # FHWA-HOP-14-032.

U.S. Department of Transportation. (2017). *Active Traffic Management (ATM) Implementation and Operations Guide.* Publication # FHWA-HOP-17-056. Retrieved from https://ops.fhwa.dot.gov/publications/fhwahop17056/index.htm#toc

U.S. Department of Transportation Federal Highway Administration. (2019). *2018 Urban Congestion Trends: Improving Operations, Improving Performance.* Publication # FHWA-HOP-19-026.

U.S. Department of Transportation Federal Highway Administration. (2020a). "High-Occupancy Toll Lanes (Partial Facility Pricing)." Retrieved from: https://ops.fhwa.dot.gov/congestionpricing/strategies/involving_tolls/hot_lanes.htm

U.S. Department of Transportation Federal Highway Administration. (2020b). "Transportation Management Centers." Retrieved from: https://ops.fhwa.dot.gov/freewaymgmt/trans_mgmnt.htm

Wainaina, P., Minang, P.A., Gituku, E., Duguma, L. 2020. "Cost-benefit analysis of landscape restoration: a stocktake." *Land* 465(9): 1-25.

Washington State Department of Transportation. (2009, October 15). *Building Smarter Highways-Active Traffic Management* [Video]. YouTube. https://www.youtube.com/watch?v=cd0doR0Ga-I

Wesselink, A. and Paavola, J. 2011. "Rationales public participation in environmental policy and governance: practitioners' perspectives." *Environment and Planning A* 43: 2688-2704.

Wijnen, W., Weijermars, W., Schoeters, A., van den Berghe, W., Bauer, R., Carnis, L., Elvik, R., Martensen, H. 2019. "An analysis of official road crash cost estimates in European countries." 113: 318-327.

Wijnen, W., Wesemann, P., de Blaeij, A. 2009. "Valuation of road safety effects in cost-benefit analysis." *Evaluation and Program Planning* 32: 326-331.

Willis, K.G., Garrod, G.D., Harvey, D.R. 1998. "A review of cost-benefit analysis as applied to the evaluation of new road proposals in the U.K." *Transportation Res. D* 3 (3): 141-156.

Vickerman, R. 2007. "Cost-benefit analysis and large-scale infrastructure projects: state of the art and challenges." *Environment and Planning B: Planning and Design* 34: 598-610.