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Transportation Asset Management for the Electric Road System

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TRANSPORTATION ASSET MANAGEMENT FOR THE ELECTRIC ROAD SYSTEM

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Dedicated to my beautiful mother.

Thank you for giving me the courage to write.

PRELIMINARY TRANSPORTATION ASSET MANAGEMENT FRAMEWORK FOR THE ELECTRIC ROAD SYSTEM

By

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THESIS

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ABSTRACT

Electric road systems (ERS) have been presented as a new solution towards a sustainable transportation future, fueling the widespread adoption of electric vehicles by eliminating range anxiety, reducing battery size, and being regional friendly. These systems consist of four components: electric power supply, roads, vehicles, and operations. Much of the early research conducted on ERS has been on how to initially construct these systems by focusing on the first three components, however, there is limited knowledge on how ERS will impact traditional road operations after the systems are in place. Transportation Asset Management (TAM), a major focus within the transportation industry, provides a methodical approach for the operation, maintenance, and improvement of road systems in a cost-effective manner. The Federal Highway Administration (FHWA) developed the Highway Economic Requirements System State Version (HERS-ST) to support TAM principles by providing a framework that explores the relationship between levels of investment and performance of highway systems. The exploration of that relationship is fundamental to the successful implementation of any new transportation infrastructure, including ERS. This study aims to develop a dynamic TAM framework for ERS modeled after HERS-ST that evaluates the economic impacts of ERS based on its long-term performance. The results of this study will provide a foundation for the economical maintenance and operations of ERS to ensure performance optimization of its lifetime. This study can also be used to anticipate how HERS-ST will need to be modified to accommodate new assets within the transportation industry.

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LIST OF ABBREVIATIONS

AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
APWA	American Public Works Association
DOT	Department of Transportation
EPA	Environmental Protection Agency
ERS	Electric Road Systems
EV	Electric Vehicle
FAST Act	Fixing America's Surface Transportation Act
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
FU	Functional Unit
GHG	Greenhouse Gas
HDV	Heavy Duty Vehicle
HERS	Highway Economic Requirements System
HERS-ST	Highway Economic Requirement System – State Version
HPMS	Highway Performance Monitoring System
I-10	Interstate 10

IAM	Institute of Asset Management
ICE	Internal Combustion Engine
IRI	International Roughness Index
ISO	International Organization for Standardization
LCA	Life-Cycle Analysis
LCP	Life-Cycle Planning
LDV	Light Duty Vehicle
MAP-21	Moving Ahead for Progress in the 21st Century Act
MDV	Medium Duty Vehicle
NCHRP	National Cooperative Highway Research Program
NHPP	National Highway Performance Program
NHS	National Highway System
NN	National Truck Network
PCC	Portland Cement Concrete
PSR	Present Serviceability Rating
STRAHNET	Strategic Highway Network
TAM	Transportation Asset Management

TAMP	Transportation Asset Management Plan
TxDOT	Texas Department of Transportation
U.S.	United States
USD	United States Dollars

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CHAPTER 1: INTRODUCTION

1.1 Background

1.1.1 The Importance of Transportation Asset Management

Transportation is often defined as the movement of people and goods, making this industry one of the most vital in the world. In the United States (U.S.), the federal government spends billions of dollars annually on improving current transportation infrastructure and developing new projects, including pavements, bridges, railroads, transit systems, ports, signs, signals, pavement markings, and so much more. Because the transportation network in the U.S. is so vast, it is important to ensure that the network's cost is low while its reliability is high. Transportation asset management (TAM) involves strategic planning to ensure the cost-effective maintenance and preservation of transportation systems to sustain high-performance levels by implementing key economic and engineering principles into the decision-making process.

1.1.2 The Shift to Sustainable Transportation Systems

In efforts to prevent environmental crises, there has been a shift towards sustainable practices. According to the U.S. National Environmental Policy Act (NEPA) of 1969, the goal of sustainability is to "create and maintain conditions, under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic, and other requirements of present and future generations." Sustainability entails addressing the environmental, economic, and social impacts of human actions. Within the transportation industry, it is crucial that infrastructure is sustainable, as systems built today can serve many generations in the future. Sustainable transportation systems are more than systems that address environmental concerns. Instead, they are systems that are safe and reliable throughout their service life and are cost-effective in terms of rehabilitation and reconstruction. TAM creates a framework for transportation agencies to ensure that investments are being made in assets that are maintained in the desired SGR for future users. With TAM, sustainability within the transportation industry becomes more feasible, as long-term funding is used strategically resulting from data-backed decisions.

1.1.3 Electric Road Systems

As part of the shift to sustainability, a major trend in the transportation industry has been electrification. Transportation electrification describes the movement from a fossil-fuel based industry to utilizing electricity as power. Using electricity results in cleaner and more efficient electric vehicles (EVs). However, the adoption of EVs has been challenging due to the limited range and high cost. A solution to further enhance the technology and fuel the widespread adoption of EVs is electric road systems (ERS). ERS are systems that enable the dynamic charging of EVs through conductive or inductive power transfer. An ERS has four main elements:

1. *Electric power supply* – The electric power supply consists of the grid or utility that provides the power, the conductive or inductive charging unit (CU) that transfers the power to the vehicles, and other electrical components, such as power cables, transformers, cooling units, and communication systems.
2. *Roads* – The road is the pavement or bridge within which the CU is embedded in or on, depending on the ERS type.

3. *Vehicles* – The vehicle component refers to EVs that benefit from the transfer of power for charging, either through direct connection or wirelessly.
4. *Operations* – The operations component involves services related to both the users and owners of ERS. This includes data management, maintenance, economics, and legal authorization.

1.2 Problem Statement

Much of the early research conducted on ERS has been on how to initially construct ERS by focusing on the first three components, however, there is limited knowledge on how these systems will impact traditional road operations after they are in place. TAM can provide a methodical approach for the operation, maintenance, and improvement of road systems in a cost-effective manner. However, as TAM is still a developing concept in the transportation industry, pavement and bridge assets are prioritized. With the addition of electrical components such as the CU embedded in/on the road due to ERS, TAM practices will need to be able to account for assets beyond the traditional road systems.

1.3 Research Objectives

The main goal of this research is to develop a dynamic TAM model that strategically integrates new assets arising from ERS and explores the relationship between lifecycle performance and investments of ERS to maximize economic benefits relative to costs. To achieve the goal of this research, the project is further divided into the following objectives:

1. To conduct a literature review of TAM, HERS, and ERS that addresses history, current work, limitations, and gaps within the areas.

2. To propose a TAM framework, based on the literature review, that strategically anticipates the key steps of the traditional TAM framework that require modification due to ERS.
3. To develop a simplified dynamic TAM model in Microsoft Excel based on HERS, which analyzes a traditional road system to ensure the validity of the model and act as a control unit. This model will be referred to as the Baseline Model.
4. To modify the Baseline Model to incorporate assets arising from ERS to evaluate the differences between the traditional TAM framework and the proposed ERS-based framework. This model will be referred to as the ERS Model.
5. To expand on the simplified ERS Model to address a national and widespread need for transportation electrification, which prioritizes assets beyond pavements and bridges and considers economic, environmental, and social benefits and costs of transportation projects.
6. To analyze the differences between each of the models developed from the previous step to evaluate how assets beyond pavements and bridges impact the TAM process.
7. To propose a dynamic TAM framework, based on the analysis of the models, that strategically incorporates ERS into each step, highlights the methods for evaluating nontraditional assets, and prioritizes sustainability.

1.4 Methodology

To achieve the goals and objectives of this research, the project is divided into three phases:

1. Phase 1, *Documentation*, focuses on objectives 1 and 2. During this phase, an extensive literature search and gap analysis will be carried out and documented for TAM, HERS, and ERS with the following respective scopes:
    a. TAM: The literature review on TAM will identify the need for TAM, the regulatory guidelines for TAMPs, and the framework for the overall TAM process. The literature review will also document any tools created to aid TAM practitioners.
    b. HERS: The literature review on HERS will identify the general framework, the major inputs and outputs of the software, advantages, limitations, and current practices within the industry.
    c. ERS: The literature review on ERS will identify the major categories of the systems, advantages, and disadvantages of each, economic costs respective to ERS lifecycles, and current practices within the industry.

    From the literature review, a preliminary TAM framework for ERS will be developed in order to begin Phase 2.
2. Phase 2, *Experimentation*, focuses on objectives 3, 4, and 5. During this phase, utilizing the knowledge gained from Phase 1, tools will be developed that model the TAM process for traditional roads versus ERS. Case studies in HERS-ST and the Excel-based TAM models will be conducted.
3. Phase 3, *Evaluation*, focuses on objectives 6 and 7. During this phase, the models developed during Phase 2 will be analyzed and evaluated to develop a new TAM framework that prioritizes assets beyond the traditional.

1.5 Thesis Organization

This thesis is divided into five chapters and two appendices.

Chapter 1 introduces TAM and transportation electrification, states the research problem, objectives, and methodology, and outlines the chapters in this thesis.

Chapter 2 provides a literature review on ERS and further investigates the inductive technology. A comprehensive TAM review is also presented in this chapter, which discusses HERS-ST in more detail. Finally, gaps and limitations within the literature are considered.

Chapter 3 presents a framework for incorporating ERS into TAM by outlining a general TAM framework and mapping ERS into it.

Chapter 4 discusses the case studies for the HERS, Baseline, and ERS Models.

Chapter 5 provides the conclusions and recommendations resulting from this research.

Appendix A provides the specific regulation for TAM under 23 U.S. Code § 119.

Appendix B outlines the HPMS fields, field description, and whether it is used in HERS-ST and in the research TAM models.

CHAPTER 2: LITERATURE REVIEW

2.1 Issues in the Transportation Industry

2.1.1 Sustainability in the Transportation Industry

The increase in travel demand in the United States (U.S.) and globally caused a large economic boom for multiple industries, including automotive and travel, however, this does not come without costs. The transportation sector accounts for 29% of the total greenhouse gas (GHG) emissions in the U.S., with passenger cars being the largest source of those emissions, followed by freight trucks, then light-duty vehicles, and finally, other forms of transportation (aircraft, rail, ships, etc.) (Environmental Protection Agency, 2022). Passenger cars alone contribute to over 780 million metric tons of carbon dioxide equivalent (MMT CO_2 eq.) of greenhouse gas emissions (Environmental Protection Agency, 2022). Additionally, the energy demand of the transportation sector is large, especially in the use of petroleum. Automotive fuels consume about 70% of the available petroleum (Elgowainy et al., 2009). Furthermore, the transportation sector has its own economic burdens, specifically the historical costs of transportation infrastructure. One cost estimation shows that as of 2008, the total expenditure on transportation infrastructure alone was over 180 billion U.S dollars (USD) (Duranton et al., 2016). To combat those issues, the transportation sector outlined two major goals:

1. Decrease GHG emissions and support sustainable development goals.
2. Develop infrastructure that is cost-effective in all stages of life, including construction and maintenance.

One major initiative in the transportation sector to reach the first goal is the development of electric vehicles (EVs). The two general types of EVs are plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs). PHEVs operate on both electricity and internal combustion, while BEVs are 100% electricity-operated (Mclaren et al., 2016). This is in comparison with conventional vehicles, which operate on 100% internal combustion. The National Renewable Energy Laboratory (NREL) conducted an analysis of the CO_2 emissions of the three previously defined vehicle types. The analysis includes four different scenarios, and the descriptions and results of each scenario can be seen in Table 1.

Table 1 - NREL Analysis Comparing Emissions of Three Vehicle Types (Mclaren et al., 2016)

Scenario	Charging Location	Charging Time	Charging Speed	Emissions on a Low Carbon Grid (lb CO_2/veh day)			Emissions on a High Carbon Grid (lb CO_2/veh day)		
				CV	PHEV	BEV	CV	PHEV	BEV
Home 1	Home	Any	Level 1	13	4.6	4.0	13	9.3	11.7
Home 2	Home	Any	Level 2		4.4	3.9		9.4	11.9
Time-Restricted	Home	12:00 AM – 1:00 PM	Level 2		4.6	3.8		9.4	12.2
Workplace	Home+ Workplace	Any	Level 2		3.9	3.5		9.5	11.8

Level 1 indicates a standard vehicle charger that uses 120 volts, while Level 2 indicates specialized charging equipment with 240 volts (Mclaren et al., 2016). This analysis shows that both the PHEV and BEV prove to be less emissive concerning CO_2, however, the results are skewed based on the electricity grid. If the grid is low-carbon intensive, then BEVs will have a lower emission rate of CO_2, and if the grid has a high-carbon intensity, then PHEVs will have an overall lower emission rate of CO_2 (Mclaren et al., 2016). It should be noted that policy changes encouraging renewable energy not only in the transportation industry, but also in the power industry will result in even fewer CO_2 emissions. Electrical grids with low carbon intensities (less than 1.5 lb CO_2/kWh) combined with the widespread use of workplace charging, and the global adoption of BEVs can significantly reduce CO_2 emissions (Mclaren et al., 2016). Because of this, there has been a major shift towards BEVs.

Although the lower GHG emissions are promising for BEVs, there is a lot of hesitation in adopting these vehicles for the user. One of the biggest concerns is "range anxiety." Range anxiety is defined as "the psychological anxiety a consumer experiences in response to the limited range of an electric vehicle" (Noel et al., 2019). A survey was conducted to discover reasons why a consumer would be disinterested in EVs, and the results show that 25% of survey takers' main concern was the EV's limited range, and the second-highest contender was the cost, with just over 15% of survey-takers choosing this option (Noel et al., 2019).

2.2 Electric Road Systems as a Solution

2.2.1 Overview of Electric Road Systems

Electric road systems (ERS) are a transportation system that can:

1. Alleviate range anxiety.
2. Significantly reduce the cost and size of an EVs battery.
3. Reduce GHG emissions of the total transportation sector.

ERS are systems that enable dynamic wireless power transfer between the vehicle and the road, which results in a charge-while-driving technique (CWD) (World Road Association (PIARC), 2018). There are three major concepts of ERS. The first two operate under conductive measures while the third uses inductive technology.

2.2.1.1 *Dynamic Conductive ERS*

As mentioned, there are two types of conductive ERS. The first is overhead conduction, which utilizes a direct connection between a pantograph and the overhead power supply (typically cables) (World Road Association (PIARC), 2018). This technology is the most mature and is similar to an advanced trolley bus system. One example of the conductive overhead ERS is Siemens' eHighway launched in Germany. The eHighway includes an overhead contact line system built on the public autobahn, which a focus on electrified freight transport (Siemens, n.d.). Figure 1 shows an image of Siemens' first eHighway.

Figure 1 - Siemens First eHighway in Germany (Siemens, n.d.)

The second type of conductive ERS utilizes a conductive rail technology. It is similar to the conductive overhead by relying on direct contact to transfer energy, however, this system uses “electrified rails embedded in or on top of the road surface” (World Road Association (PIARC), 2018). One implementation of this system is Elways’ eRoad located in Stockholm. The eRoad consists of a direct feed from the vehicle to an electrified rail embedded on top of the road (Elways, n.d.). Figure 2 shows a close-up of Elways’ eRoad rail system.

Figure 2 - Elways' eRoad system (Elways, n.d.)

2.2.1.2 Dynamic Inductive ERS

Dynamic inductive ERS differ from conductive ERS in that the power transfer is not direct and instead is wireless. This concept includes a power transfer from primary coils embedded in the road to the secondary coils located on the vehicle (World Road Association (PIARC), 2018). A leader in the field of dynamic inductive ERS is a group called Electreon, which currently has projects in Israel, Sweden, Italy, and Germany (Electreon, n.d.). These systems include under-road units (copper coils under asphalt roads), a management unit (transfers energy and manages communication), the vehicle (equipped with energy receivers), and a central control unit (CCU) (cloud service) (Electreon, n.d.). Figure 3 shows an example of Electreon's inductive ERS system.

Figure 3 - Electreon's smart road technology underway in Gotland, Sweden
(Electreon, n.d.)

Table 3 below outlines the key differences between conductive overhead, conductive rail, and inductive ERS.

Table 2 - Comparative Analysis of General ERS Types (PIARC, 2018)

	Dynamic-inductive	**Conductive overhead**	**Conductive rail**
Components	-*In road*: primary coils and power cables -*On-vehicle*: secondary coils, electric drive train components, and control electronics -*Roadside*: grid connections, power inverters, transformers,	-*On-vehicle*: pantograph, electric drive train components, and control electronics -*Roadside*: power cables, power	-*In-road*: electrified rail system (embedded in or on the road) -*On-vehicle*: pantograph, electric drive train components, and control electronics -*Roadside*: transformers, grid

	cooling units, communication systems	transformers, communication systems	connections, communication systems
Vehicle Application	-Suitable for most vehicle types	-Heavy-duty vehicles	-Suitable for most vehicle types
Benefits	-No visual impact -Safer for road users -Less vulnerable to natural or human-caused damages	-Provides high levels of power -Most mature technology -Has no impact on the road or routine pavement maintenance activities	-Provides high levels of power -Can be easily accessed for maintenance
Challenges	-Not easily accessible for maintenance activities -Impact on the surrounding road is unknown	-High visual impact -May be an obstacle to emergency responders -Vulnerable to natural or human-caused damages	-Safety concerns for road users -Vulnerable to natural or human-caused damages

2.2.2 A Deeper Look into Inductive Electric Road Systems

Although inductive WPT in transportation can be traced back to the late 1800s, major academic interest in the topic grew in 1991 when researchers at the University of Auckland developed a systematic approach to individually identifying and improving each component of a WPT system (Covic et al., 2013). They noted that those systems generally included four elements: power supply, power track, pickup system, and controller for the power transfer process (Covic et al., 2013). The WPT system was then implemented into the transportation infrastructure to create an ERS.

Figure 4 illustrates the general placement of the CU by embedment type. As previously stated, inductive ERS typically includes in-road, on-vehicle, and roadside components. The in-road components are embedded in the road, either in prefabricated units or on-site placement. With prefabricated units, the inductive CU is placed in a precast slab and later embedded into the road at the site as a whole unit. On-site placement of the CU consists of individually placing the skeletal components directly into the road at the site.

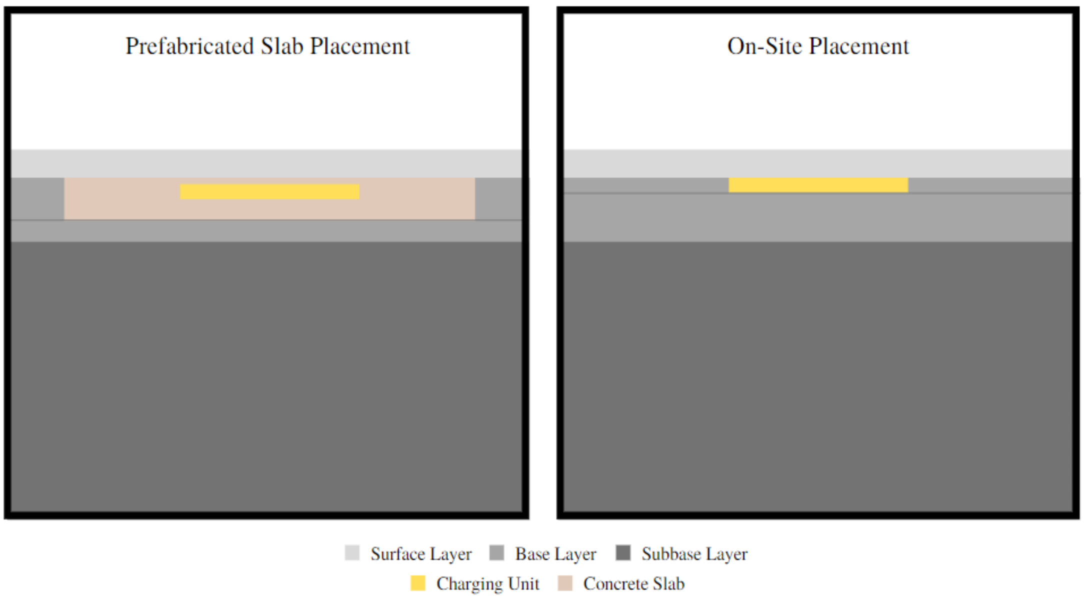

Figure 4 – Representation of CU Embedment Types (Not to Scale)

The construction of the roads can either be trench-based or full lane-based. The trench-based method consists of creating a trench in an existing road, laying the CU, then backfilling and resurfacing with an asphalt layer (Marmiroli et al., 2019). Full lane-based construction involves removing the top layers of the road, laying the CU, then resurfacing with an asphalt layer (Marmiroli et al., 2019). The trench-based alternative is quicker and initially more cost-effective than the other method, although trench-based construction can require the use of more longitudinal joints, potentially resulting in higher maintenance costs (Marmiroli et al., 2019). The methods of CU embedment and construction are determined by the location, type of road, type of CU, and other deciding parameters. The impact of each construction method and embedment type on the surrounding road is still under review.

2.2.3 Ecological Assessments of WPT in ERS

2.2.3.1 Comparison of Dynamic WPT versus Static WPT versus Plug-In Charging

Bi et al. (2019) evaluated the performance of dynamic WPT (DWPT) in comparison to stationary WPT (SWPT) and conventional plug-in charging. They analyzed 11 different scenarios, which varied based on whether they included plug-in charging, SWPT at home/public parking, SWPT at traffic lights, DWPT, solar panels and storage batteries at the roadside, Michigan-based electricity grid and fuel, California-based electricity grid, and fuel, and a boost in EV sales versus base EV sales. The purpose of using the California grid and fuel data was to evaluate the impact of incorporating perceived clean energy. The LCA was conducted over a 20-year scope with a functional unit (FU) defined by the total vehicle miles traveled (VMT) on the arterial roads within Washtenaw County, Michigan using SimaPro. They showed that all scenarios with DWPT emitted a lower amount of GHG than the scenarios without it. The solutions with solar panels and storage batteries further reduced the GHG emissions and energy burdens throughout the infrastructure's lifetime. Bi et al. (2019) also noted that electrifying just 3% of the total roadway in the region would decrease the battery size of the EVs compared to the plug-in charging solution. The solutions containing "DWPT + Solar + CA" resulted in the least GHG emissions and lifecycle energy demands. They showed that DWPT was more environmentally sustainable than stationary and plug-in charging solutions. The most sustainable ERS infrastructure utilized both SWPT and DWPT solutions, along with roadside solar panels, in the optimal locations to decrease infrastructure and battery costs, boost EV sales, and lower the environmental impact of the transportation sector.

2.2.3.2 Comparison of ERS Alternatives

Nádasi (2017) conducted an LCA and case study for electrified roads (eRoads) in Sweden using SimaPro. The study compared the environmental impacts of the three ERS alternatives using a cradle-to-gate model that analyzed the production, construction, and maintenance phases over a 20-year lifetime. The study assumed that a new asphalt eRoad will be constructed next to an existing highway in Europa, Sweden. The eRoad was assumed to be 3.5 m wide by 10 km long, which is also defined as the FU. The road analyzed consisted of three layers: surface course (4 cm), binder course (9 cm), and base course (10 cm). For the inductive solution, the CU was embedded in a 200 mm thick and 800 mm wide concrete box that spanned across the entire road. After conducting the life cycle inventory analysis (LCIA) and inputting the model into SimaPro, all three alternatives had a significant impact on the environment. The climate change impact of the conductive rail solution was three times as high as a traditional road, the conductive overhead solution was over 7,000 times as high, and the inductive solution was over 9,000 times as high. The researchers also conducted a sensitivity analysis to determine whether the use of copper and the amount of winter maintenance could affect the climate change impact. The results showed that the conductive rail and overhead solutions remained the same, while the inductive solution's climate change impact decreased to just over 4,000 times as high as that of a traditional road. The study contained some uncertainty, though. The model did not consider the widespread electrification of vehicles that would replace traditional internal combustion engine (ICE) vehicles and ultimately reduce the amount of GHG emissions of the transportation sector altogether. Also, the model made many assumptions about the electrical components of the CUs in all three alternatives. For the inductive solution, the only CU materials considered were copper cables and the concrete box in which the cables were embedded. Finally, maintenance and operational works were assumed for the model during the 20-year lifetime, as information about these phases of ERS was unknown. Despite the limitations, the researcher concluded that the conductive rail solution was the least impactful on climate change, while the inductive solution was the most impactful unless copper usage was decreased, and winter maintenance was increased.

Balieu et al. (2019) also compared the life cycle impacts of the three ERS alternatives in Sweden. In their cradle-to-gate model, they evaluated the CO_2 impacts during the construction, operation, and rehabilitation phases of a 1 km road over a 20-year lifetime. The asphalt pavement consisted of three layers: surface course (4 cm), binder course (9 cm), and base course (10 cm). The inductive solution used in that study was POLITO's CWD, which consisted of coils embedded in concrete blocks, using about 500 coils per FU. However, the detailed electrical components of the CU for any alternative were not used in the LCA. The LCA analysis revealed that throughout the ERS lifecycle, the conductive rail solution resulted in the least CO_2 impact, followed by the inductive solution and then the conductive overhead solution. All three alternatives resulted in CO_2 impacts that were less than twice as much as a traditional road. However, based on another study by the same authors (Chen et al., 2018), the inductive solution is most vulnerable to damages after several passes by heavy vehicles. Taking that into consideration, the researchers determined the CO_2 impacts of the ERS alternatives with increased winter maintenance and rehabilitation. The conductive rail solution still had the least CO_2 impact, although this time it was twice as much as that of a traditional road. Unlike the previous results, the inductive solution had the highest CO_2 impact, which was over twice as much as a traditional road. These impacts are a lot less than those of the previous study (Nadasi, 2017), which can be attributed to the difference in the FU. However, both studies show that the inductive solutions are most ecologically impactful compared to the conductive alternatives.

2.2.3.3 Comparison of Electric Road versus Traditional Road

Marmiroli et al. (2019) assessed the construction and maintenance phases of dynamic WPT in eRoads at a test site in Susa, Italy. The project was in partnership with the "feasibility analysis and development of on-road charging solutions for future electric vehicles" (FABRIC) project, intending to determine the environmental impact of the construction and maintenance of eRoads over a lifetime of 20 years. The eRoad analyzed was 25 km long in both directions with the following layers: wearing layer (6 cm), binder layer (7 cm), base course (32 cm), and subbase course (15 cm). The CU was embedded in low-stiffness concrete and placed 6 cm below the road's surface, which was in the binder layer and right under the wearing layer. Unlike the LCA conducted by the previous two studies (Bi et al., 2019 and Nadasi, 2017), this assessment included a comprehensive inventory analysis of not only the roads but of the CU components as well. EcoInvent was used to conduct the LCA. The study assessed the climate change impact, cumulative energy demand (CED), and AD-fossil fuel. Although the CU components accounted for less than 1% of the total materials used, they largely contributed to the climate change, CED, and AD-fossil fuel impacts, representing 64%, 31%, and 27% of each category, respectively. The results showed impacts in all three categories that were twice as much as the impact of a traditional road, including the climate change impact which is significantly less than the results of the study carried out by Nádasi (2017) and somewhat similar to the study conducted by Balieu et al. (2019). The difference could be attributed to the fact that this study analyzed the eRoad in-depth and utilized data from FABRIC's test site at Susa, Italy, while the CU data from Nádasi (2017) were largely assumed. However, all three studies showed that the ecological impacts of the eRoad are higher than that of a traditional road.

Quinn et al. (2015) conducted a techno-economic analysis of inductive WPT to determine the societal payback period of ERS and EVs compared to traditional roads and vehicles. The researchers modeled different vehicle types: ICE vehicles, WPT vehicles, and heavy trucks (with power systems similar to the ICE and WPT vehicles). While the focus of that study was on the economic impacts, an environmental analysis was also performed. The analysis considered the GHG emissions and emissions of the criteria pollutants: VOC, CO, NOx, PM10, PM2.5, and SOx. The environmental analysis resulted in CO_2 emissions of electrified transportation, almost half of traditional transportation, which contradicted the previously described studies perhaps due to the additional analysis of the vehicles in this study. The widespread shift of ICE vehicles to EVs resulted in a significant decrease in emissions. The electrified transportation emissions of the criteria pollutants were also lower for all except SOx. This is due to coal-based power representing approximately 39% of the power for electrified transportation infrastructure. That study showed the viability of ERS and EVs as opposed to traditional roads and vehicles.

2.2.3.4 Discussion of Ecological Feasibility of ERS

When comparing different sustainable transportation solutions, DWPT results in lower GHG emissions than SWPT and plug-in charging throughout their respective life cycles (Bi et al., 2019). As such, dynamic-inductive charging for EVs could be considered more environmentally friendly than stationary and plug-in charging solutions. However, the studies by Nádasi (2017) and Balieu et al. (2019) both showed that out of the three ERS alternatives, the inductive solution was the least environmentally friendly, although all three had a higher climate change impact than a traditional road. Nádasi (2017) determined that decreasing the use of copper and increasing the winter maintenance of the ERS alternatives would lower the climate change impact of the inductive solution. Balieu et al. (2019) found that increasing the winter maintenance increased the inductive solution's impact, although that study did not consider the usage of copper in the CU's production. The high impact of the inductive solutions can be attributed to the construction and maintenance phases, requiring significant work for implementing and rehabilitating the infrastructure. The analyses by Nádasi (2017), Balieu et al. (2019), and Marmiroli et al. (2019) did not consider the impact of widespread transportation electrification on the environment. Although constructing and maintaining the ERS infrastructure will undoubtedly emit GHGs, the amount is small compared to the GHG savings that will result from the ERS throughout the entire lifecycle. Inductive ERS is suitable for most vehicle classes, meaning a majority of vehicles can then transform into EVs. The study by Quinn et al. (2015) determined that by converting just about 20% of traditional roads and vehicles to inductive ERS and EVs would result in half as much GHG emissions than a scenario with only traditional transportation infrastructure. The existing environmental LCA studies lack an analysis that considers all components of ERS, which includes the vehicles as well. Because the inductive solution is best suited for a majority of vehicle types, the usage of fossil fuels and emission of GHGs will significantly decrease, possibly even more so than the

2.2.4 Economic Feasibility of ERS

The LCA by Bi et al. (2019) also determined the economic performance of DWPT compared to SWPT and plug-in charging. Again, that study assessed 11 different scenarios that varied based on the charging type, the addition of solar panels and battery storage, Michigan or California-based grid and fuel, and EV sales. The results showed that DWPT had a minor positive effect on the life-cycle costs compared to the SWPT and plug-in charging solutions. They also found that the initial investment costs of the infrastructure were high, especially with the additional solar solution and California-based fuel prices. The increase in costs for the California-based solutions was also a result of California fuel prices being higher than Michigan's fuel prices. Deploying and maintaining the DWPT infrastructure will take up anywhere from 2.3-4.2% of lifecycle costs depending on the infrastructure type. Bi et al. (2019) found that during a 20-year timeline, the net profit of money flow from DWPT infrastructure will remain negative. The cost breakeven time for the infrastructure is projected to be over 20 years, due to the heavy initial burdens. Results also showed that a 50% reduction in the infrastructure burdens will shorten the breakeven period for GHG emissions and energy, but the net profit of money flow for DWPT infrastructure will remain negative throughout a 20-year timeline. Because of the results, Bi et al. (2019) recommend large-scale and aggressive early deployment of DWPT infrastructure to influence the widespread growth of EVs. This growth will result in lower EV battery sizes, which could potentially reduce costs. It should also be mentioned that once the DWPT lifecycle costs are paid back, operational revenues from the infrastructure can be significant.

The study by Quinn et al. (2015) considered the economic impact of ERS and EVs compared to traditional transportation infrastructure and vehicles. As previously mentioned, that study analyzed several scenarios that differed based on the utilization of WPT vehicles, ICE vehicles, WPT trucks, and ICE trucks. The cost assumptions were as follows:

1. ICE vehicle: purchase price of USD $31,252 with the maintenance cost of 8% of the purchase price over the vehicle's lifetime
2. WPT vehicle: purchase price of USD $21,877 with the maintenance cost of 4% of the purchase price over the vehicle's lifetime
3. Truck: purchase price of USD $250,000 with the maintenance cost of either 8% or 4% of the purchase price over the vehicle's lifetime, depending on whether the vehicle has an ICE or WPT system
4. Infrastructure: upgrade costs of USD $2.4 million per lane per mile

5. Fuel: baseline of USD $4.07 per gallon
6. Electricity: baseline of $0.107 kW/hr.

The study assessed the societal payback periods for interstate roadways only and both interstate and urban roadways with different levels of market penetration of EVs. The payback period is the amount of time for the cost of the infrastructure to be repaid through cost savings of the operation, maintenance, and purchase of WPT components, vehicles, and infrastructure. The payback periods are analyzed as a function of the market penetration rate of the WPT infrastructure and vehicles. With a market penetration rate of 20%, electrifying both interstate and urban roadways would result in a societal payback of 2.6 years while electrifying only interstate roads showed a societal payback of just about one year. The scenario including both interstate and urban roadways, resulted in a higher payback period than the scenario considering only interstates for all market penetration rates due to the additional amount of infrastructure. Another influencing factor of the payback year is the price of fuel. For instance, the higher the price of fuel is, the higher the payback year will be. However, the results of this study contrast those of the study by Bi et al. (2019), which determined a breakeven period of over 20 years. This difference can be attributed to many different factors. The study conducted by Bi et al. (2019) compared scenarios based on the type of charging infrastructure (DWPT, SWPT, and plug-in charging) while the study by Quinn et al. (2015) only compared DWPT infrastructure with traditional infrastructure. Also, the results of the analysis Quinn et al. (2015) are based on market penetration rates of the electrified infrastructure and vehicles. Overall, Quinn et al.

(2015) shows the sustainable viability of eRoads with a minimal societal payback period with a higher market penetration rate.

Domingues-Olavarría et al. (2018) analyzed the societal cost of electrifying all Danish road network. The Danish automotive fleet consisted of 3.3 million vehicles, varying from light-duty vehicles, buses, distribution trucks, and heavy-duty vehicles. Denmark's total length of the road network is about 73,500 km, with just over 4,500 km being highways and carriageways. The analysis included five scenarios:

1. Large batteries – electrification is achieved through the sole use of batteries. The battery capacities range by vehicle type (light-duty, buses, distribution trucks, and long-haul trucks).
2. Overhead electric road – electrification is achieved through conductive overhead systems on all major roads in Denmark, suitable for long-haul trucks and coach buses only.
3. Road bound inductive – electrification is achieved through inductive systems on all major roads in Denmark, suitable for long-haul trucks, coach buses, light-duty vehicles, city buses, and distribution trucks.
4. Road bound conductive – electrification is achieved through conductive road systems, suitable for long-haul trucks, coach buses, light-duty vehicles, city buses, and distribution trucks, similar to scenario 3.

The costs of the conductive solutions were based on data obtained from a test site in Sweden, while the costs of the CU components and infrastructure installation for the inductive solution were estimated based on a potential project. The projected maintenance costs were proportional to the cost of deployment for each solution, although the data were largely assumed. Additionally, the costs of the batteries, fuel, and electricity were based on figures current to Denmark around the time of the study. They found that scenarios 1 and 2 barely breakeven and were not yet cost-effective due to the battery size. Both road-bound solutions had a significantly less breakeven period, although the inductive solution was slightly higher than the conductive. If an entire vehicle fleet is electrified, which included both light-duty and heavy-duty vehicles, the societal cost decreases dramatically.

PIARC (2018) conducted a cost-benefit analysis to estimate the payback time on the investments made for each ERS alternative. Their Microsoft Excel-based model compared electricity mark-up rates of 10% and 65%. The mark-up is a margin charged by the operator to vehicle users on top of the electricity supply tax and stayed consistent over a 20-year timeline. The model also assessed technology penetration rates. For both light- and heavy-duty vehicles, the annual take-up rate was 5%, and so was the assumed initial percentage of the electrified vehicles. They also had a limit to the technology penetration, which was 30% for light-duty vehicles and 75% for heavy-duty vehicles.

PIARC (2018) made the following assumptions based on their literature review:

1. Inductive – minimum of 445 k£/lane/km and maximum of 4,348 k£/lane/km
2. Conductive overhead – minimum of 1.99 M£/lane/km and maximum of 2.31 M£/lane/km

3. Conductive rail – minimum of 401 k£/lane/km and maximum of 1.335 M£/lane/km

With an electricity mark-up of 10%, none of the ERS alternatives have a break-even year lower than 20 years. Also, none of the alternatives pointed to positive cost savings after 20 years. With an electricity mark-up of 65%, only the minimum cost inductive scenario and both conductive rail scenarios had a breakeven year of fewer than 20 years. The inductive solution with the minimum cost had a breakeven period of 6 years and resulted in savings of over 5.7 M£ after 20 years. The savings after 20 years for the minimum inductive scenario was higher than both conductive rail solutions.

PIARC (2018) also conducted a review of existing ERS throughout the world. Table 3 provides their breakdown of the cost estimations for existing dynamic-inductive ERS. The table includes the name of the product, organization, country of origin, technology readiness level (TRL), vehicle application, and cost. A TRL of 3-4 means that there has been lab testing and proof of the concept has been developed. A TRL of 5-6 means that prototypes have gone through demonstration and the technology was evaluated under different environmental stresses. Finally, a TRL of 9 means that the system has been thoroughly tested and has been successfully operated. The dynamic-inductive ERS range anywhere from lab developments to a few that are successfully operating. The lowest cost is the On-Line Electric Vehicle (OLEV) by Dongwon Inc. and the Korea Advanced Institute of Science and Technology (KAIST), which is €500,000/lkm (approx.. USD 590,000/lkm). All other solutions are greater than €1M/lkm (approx.. USD 1,180,000/lkm). However, as all solutions are continually tested and improved, the prices could vary once finalized.

2.2.4.1 Discussion of Economic Feasibility of ERS

The study that compared DWPT to SWPT and plug-in charging (Bi et al., 2019) determined that DWPT resulted in higher lifecycle costs and a breakeven period that was greater than 20. However, the scenarios of this analysis that included DWPT also factored in that either SWPT or roadside solar panels would also be deployed at the same time. None of the 11 scenarios analyzed assessed DWPT by itself, which could also have an influence on the higher costs. It is important to mention that Bi et al. (2019) recommended deploying all infrastructure to result in the highest lifecycle emissions savings, even though the lifecycle costs would be high. Also, the revenue generated after the breakeven point was reached could be significant. Next, Quinn et al. (2015) compared the costs of inductive ERS to traditional roads and found that the payback year is dependent on the market penetration rate of the WPT infrastructure. For example, if the infrastructure was deployed at a rate of 20% on interstate roads, the payback period would be only about one year. The difference between the studies by Bi et al. (2019) and Quinn et al. (2015) may be in each study's definition of breakeven or payback year and the factors involved, such as the type of infrastructure modeled and the cost assumptions used. Finally, the study by Domingues-Olavarría et al. (2018) and PIARC (2018) both compared the costs of implementing the three ERS alternatives. They were similar in finding that the inductive and conductive rail solutions resulted in the smallest breakeven year. PIARC (2018) found that an inductive solution with a cost of 445 k£/lane/km can have a breakeven year of just six and also results in over 5.7 M£ in savings after 20 years. That amount of savings was higher than the projected amount for all other alternatives. This shows that dynamic-inductive ERS has the potential to be economically viable, although more research on this area should be done.

2.3 Transportation Asset Management

2.3.1 Background and History

2.3.1.1 Laws and Regulations

Various transportation funding bills establish the requirement of state TAM plans (TAMP). Each state is required to submit TAMPs to the FHWA which will be reviewed and certified to ensure compliance with the following laws and regulations.

23 U.S. Code § 119 – National Highway Performance Program (NHPP)

The 23 U.S. Code § 119 establishes a national highway performance program (NHPP) to provide support for the improvement of the NHS, including preservation of existing systems and construction of new transportation infrastructure. The code specifically requires that "A State shall develop a risk-based asset management plan for the National Highway System to improve or preserve the condition of the assets and the performance of the system" (National Highway Performance Program, 2012). The state TAMP is required to list the pavement and bridge assets on the NHS in the state, outline the objectives and measures, identify performance gaps, conduct lifecycle cost and risk management analyses, contain a financial plan, and propose investment strategies (National Highway Performance Program, 2012). The full TAM requirements of 23 U.S. Code § 119 are outlined in Appendix A.

Moving Ahead for Progress in the 21st Century (MAP-21) Act

MAP-21 was signed into law in 2012 to provide transportation funding to improve the transportation network in the U.S. Under this act, the NHPP is authorized, in which the asset management requirements are outlined. A key focus of MAP-21 is performance-based management strategies that efficiently utilize funds for transportation projects (FHWA, 2012).

Fixing America's Surface Transportation (FAST) Act

The FAST Act was signed into law in 2015 to build upon MAP-21 and provide further funding for surface transportation projects. Like MAP-21, the FAST Act supports the NHPP, providing $23.3 billion USD to ensure quality condition and performance of transportation assets. This act also allows states to allocate funding to improve or preserve bridges if they are on highways that receive federal aid (FHWA, 2016).

2.3.2 Definitions

Many organizations define asset management in different ways, listed in Table 1 below. The table includes definitions from the American Association of State Highway and Transportation Officials (AASHTO), Federal Transit Administration (FTA), Institute of Asset Management (IAM), American Public Works Association (APWA), Environmental Protection Agency (EPA), and International Organization for Standardization (ISO). It can be seen from the following definitions that key themes of asset management are risk management, performance management, life-cycle planning, and achievable objectives for a desired state of good condition.

Table 3 – Definitions of Asset Management

Reference	Definition
AASHTO, 2009	"Transportation Asset Management is a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their life cycle. It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision making based upon quality information and well-defined objectives."
FTA, 2012	"Transit asset management is the strategic and systematic practice of procuring, operating, inspecting, maintaining, rehabilitating, and replacing transit capital assets to manage their performance, risks, and costs over their life cycles, for the purpose of providing safe, cost-effective, and reliable public transportation."
IAM, 2015	"Asset management involves the balancing of costs, opportunities and risks against the desired performance of assets to achieve an [organization's] objectives."
MAP-21, 2012	"[…] a strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on engineering and economic analysis based upon quality information, to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair over the lifecycle of the assets at minimum practicable cost."
APWA, 2018	"The systematic and coordinated activities and practices of an [organization] to optimally and sustainably deliver on its objectives through the cost-effective lifecycle management of assets."
EPA, 2022	"Asset management is the practice of managing infrastructure capital assets to minimize the total cost of owning and operating them, while delivering the service level customers desire. This management framework has been widely adopted by the water sector as a means to pursue and achieve sustainable infrastructure."
ISO 55000	"Coordinated activity of an organization to realize value from assets."

2.3.3 Key Themes

2.3.3.1 Risk Management

The FHWA defines risk as the "positive or negative effects of uncertainty or variability upon agency objectives" (FHWA, 2012). Risk management is a vital component of TAM to prevent threats to assets such as failures due to faulty construction, extreme weather, and/or traffic accidents. It also includes documentation of potential risks and decisions arising from risk analyses in order to understand how to effectively deal with future threats to the assets (FHWA, 2012). Ideally, risk-management as a step in TAM will result in control over asset costs and project schedules and will reduce the potential for negative outcomes throughout the assets' lifecycle (D'Ignazio, 2011).

2.3.3.2 Performance Management

MAP-21 shifts to a focus on performance-based planning within the transportation industry. Performance-based planning bridges the gap between asset management and long-term policy and investment decisions made by decision-makers. Working at a system level, performance management utilizes data-driven strategies to define goals and evaluate long-term processes to achieve them (FHWA, 2022). 23 CFR 515.7 requires that state TAMPs clearly identify how they will focus on the following:

1. "Improving or preserving the condition of the assets and the performance of the NHS relating to physical assets," and
2. "Achieving the State DOT targets for asset condition and performance of the NHS in accordance with 23 U.S.C. 150(d)."

2.3.3.3 Life-Cycle Planning (LCP)

According to 23 CFR 515.5, life-cycle planning (LCP) is a process used to estimate and minimize the cost of managing an asset over its entire life cycle while preserving or improving its condition. LCP for an asset's life-cycle should consider initial construction, preservation, maintenance, rehabilitation, reconstruction, and disposal by estimating future traffic demand, environmental activity, and other factors that could impact the cost of the asset (FHWA, 2019). By taking a life-cycle approach, the outcome of TAM will include stronger data and long-term performance analyses and an understanding of the return on investment for the asset (FHWA, 2019).

2.3.4 Framework

The typical TAM framework is expressed in Figure 1. Each step is composed as follows (FTA, 2009), with examples from the Texas Department of Transportation (TxDOT) TAMP:

1. Goals and objectives: The goals of TAM are to deliver the right projects, optimize performance, preserve assets, and promote safety, among others.
2. Asset Inventory: Asset inventorying is done to communicate the type and location of assets. TxDOT maintains asset inventory using GRID (roadways) and NBI (bridges).
3. Asset Condition: Visual surveys and automated data collection are used to determine the condition of roads and bridges.
4. Evaluate Alternatives: Engineering and economic assessments, such as LCP, BCA, and Risk Analyses, are conducted to establish a long-term focus on improving and preserving the system(s).

5. Project Prioritization and Selection: Based on the results from the previous step, projects would be selected based on the user's goals and available funding.
6. Project Implementation: Once the decision-making occurs, projects would take place in the prioritized order (resurfacing, widening, adding lanes, reconstruction, new infrastructure, etc.)
7. Performance Monitoring: Monitor the performance and condition of all assets and repeat the process for each funding period or as needed.
8. Budget Allocation: Estimate the budget when defining the goals and allocate funding to appropriate projects after the decision-making process.

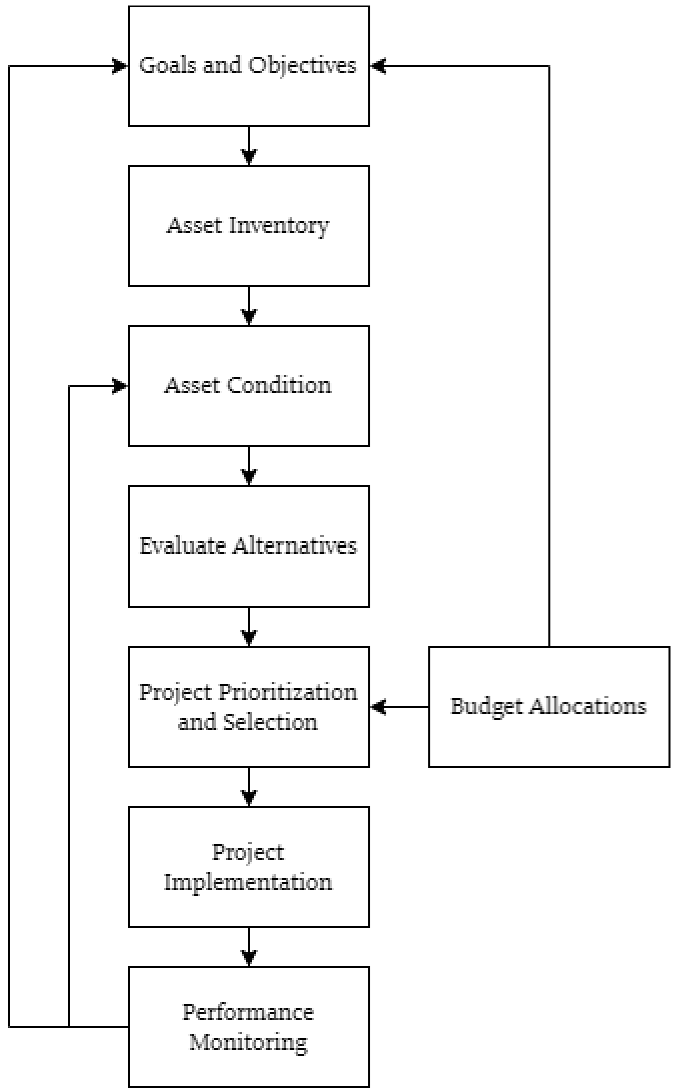

Figure 5 – TAM Framework (Adapted from AASHTO, FHWA, and FTA)

2.3.5 Highway Economic Requirements System – State Version

2.3.5.1 Overview

The FHWA developed HERS in 2002 in order to assist with analyzing investment strategies for highways based on benefits and costs. This system is helpful in the TAM process. HERS utilizes engineering and economic principles to determine the impact of highway investment levels and projects on condition, performance, and user effects of the assets (FHWA, 2014). HERS-ST conducts analyses similar to HERS at a state-level.

2.3.5.2 *Framework*

HERS-ST uses highway section datasets as an input and determines whether or not an improvement to those sections is needed. If so, HERS-ST moves on to determine what type of improvement is recommended based on several costs and benefits. Figure 2 shows a high-level overview of the HERS-ST framework, with each step described as follows (FHWA, 2014):

1. Inputs:
    a. Control Settings: The control settings allow the user to specify criteria such as the objectives and methods of the analysis. These settings control the analytical procedures of HERS-ST.
    b. Parameter Settings: The parameter settings allow the user to set the engineering and deficiency standards. In these settings, the user will also input the cost information, if any.
    c. Output Settings: The output settings allow the user to specify which information should be captured from the analysis. Although these settings are not required, they help the user to narrow down the scope of the evaluation.

d. Highway Data: HERS uses the Highway Performance Monitoring System (HPMS) data as an input. More information about HPMS is described in section 2.4.5.3.

2. Initial Setup:
3. Analytical Procedures:
   a. Current Conditions: The HPMS highway data inputted by the user acts as a starting point for the system. HERS-ST analyzes the HPMS data to determine the condition of the section as it is during the base year.
   b. Traffic Growth: The HPMS data provides information on base year traffic volume and estimates of future traffic volumes in a given year. In this step, the travel forecast is adjusted based on changes in volume and user impacts due to improvements.
   c. Future Conditions and Performance: The previously determined traffic growth information is used to forecast future conditions such as traffic, volume-to-capacity (V/C) ratios, and pavement condition. The future conditions and performance determine when an improvement will be needed.
   d. Deficiency Identification: Deficiencies in pavement condition, V/C ratios, surface types, lane width, shoulder width, shoulder type, curves, and grades and checked.

e. Potential Improvement Identification: Based on the deficiency identification, HERS-ST determines what type of improvements will correct the deficiencies.

f. Improvement Selection: HERS-ST implements engineering and economic principles, such as benefit-cost analysis, to determine the best set of improvements for each highway section. The improvements are selected based on user, agency, and societal costs and benefits over the life of the improvement and the total cost of implementing the improvement.

4. Outputs:

   a. System Conditions: The system conditions section contains summary data on the system's initial conditions as well as its state at the end of each funding period.

   b. Improvement Statistics: The improvement statistics summarize the implemented improvements for each funding period as well as the whole analysis period.

   c. Section Conditions: The section conditions contain information about the status of each section at the end of the funding period, as well as information about selected improvements and their effects.

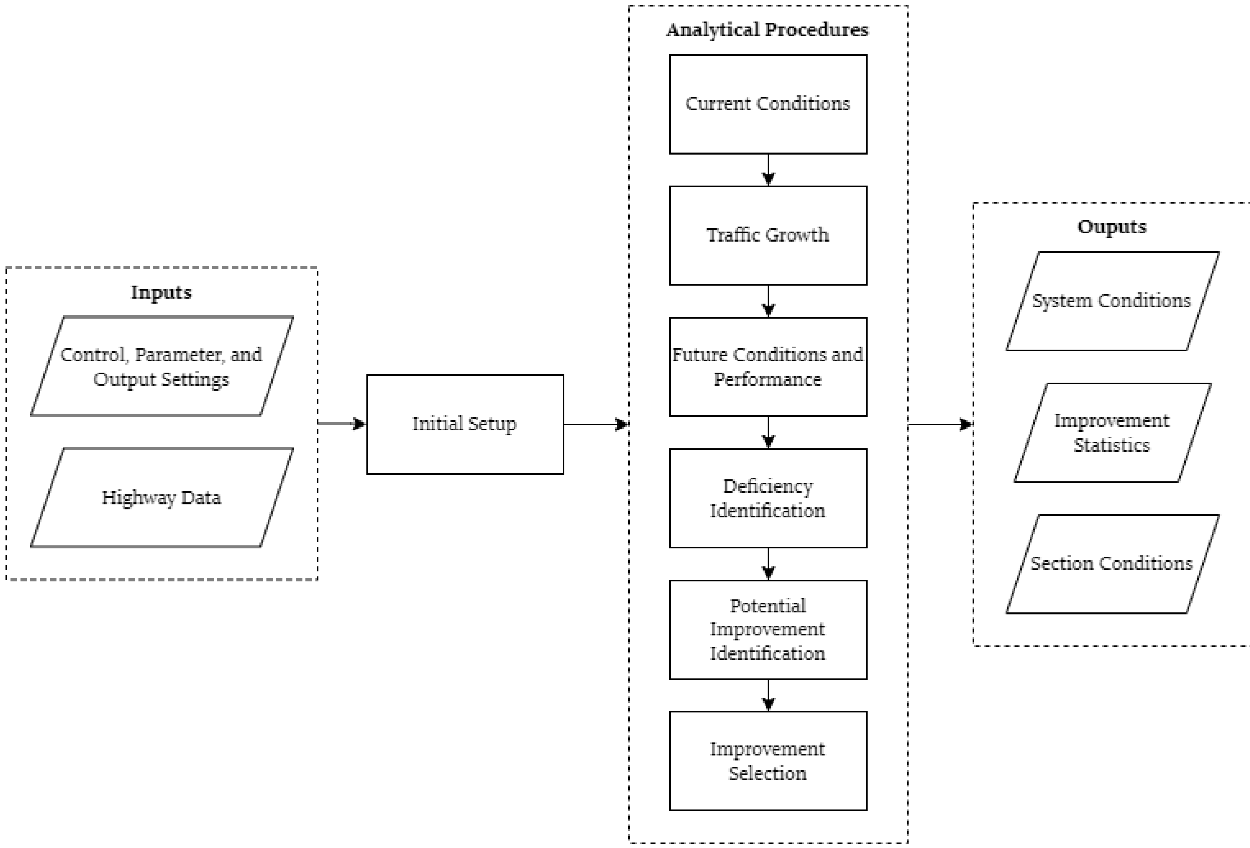

Figure 6 – HERS Framework (Adapted from FHWA, 2014)

2.3.5.3 Highway Performance Monitoring System

HERS-ST uses HPMS data as an input for highway information. HPMS, developed in 1978, is an information system that contains data on the extent, condition, performance, use, and operating characteristics of U.S. highways (FHWA, 2021). With over 90 data parameters, HPMS provides information on section inventory, route, traffic, geometry, pavement, and special networks. All fields are described in Appendix B, however, examples are as follows (FHWA, 2016):

1. Inventory: Functional System, Urban Code, Facility Type, etc.
2. Route: Route Number, Route Signing, Route Qualifier, etc.

3. Traffic: Annual Average Daily Traffic (AADT), K-Factor, Future AADT, etc.
4. Geometry: Lane Width, Median Type, Shoulder Type, etc.
5. Pavement: International Roughness Index (IRI), Present Serviceability Rating (PSR), Rutting, etc.
6. Special Networks: National Highway System (NHS), Strategic Highway Network (STRAHNET), National Truck Network (NN), etc.

2.4 Discussion

Dynamic-inductive ERS is a feasible solution to decreasing the ecological and economic burdens of the transportation industry. The existing analyses of inductive ERS show varying results though. Comparing LCAs on ERS is difficult due to many differences, such as location, infrastructure type, FU used, project scope, and much more. On one hand, some LCAs resulted in inductive ERS having a higher ecological impact than both conductive ERS alternatives and traditional transportation infrastructure. However, because existing data on the CU is difficult to obtain, a lot of assumptions in the LCAs had to be made. Also, many studies did not consider the impact of widespread electrification of vehicles in the LCA. The shift from ICE vehicles to EVs will also decrease GHG emissions in the industry significantly. One study (Quinn et al., 2015) shows that higher market penetration rates of both the ERS infrastructure and EVs will result in fewer CO_2 emissions throughout the lifecycle.

The varying results are also true for the economic analyses. For instance, Bi et al. (2019) showed that the payback period for inductive ERS was longer than 20 years, however other studies resulted in payback periods of 1 year (Quinn et al., 2015) and six years (PIARC, 2018). Again, there is difficulty in comparing the analyses due to a difference in each project's scope and objectives. However, the literature shows that inductive solutions have great potential in advancing sustainability in the transportation industry across the ecological and economic spectrum. Because this technology is relatively new, further research is needed. While the economic analyses on ERS are already limited, there lacks little to no research on TAM for new technologies. It is important that methods to incorporate ERS into existing TAM applications are explored in order to prepare for future needs.

CHAPTER 3: DEVELOPMENT OF AN EXCEL-BASED TRANSPORTATION ASSET MANAGEMENT MODEL FOR ELECTRIC ROAD SYSTEMS

The literature review presented in Chapter 2 informs the preliminary TAM framework for ERS. The following discusses how each step of the base TAM framework may be modified in order to incorporate ERS components.

1. Goals and objectives: The goals of each key stakeholder of ERS need to be aligned in order to develop an effective TAMP for the systems.
2. Asset Inventory: With the inclusion of ERS, a database is needed to account for system components embedded in or on the roadways.
3. Asset Condition: A condition assessment and rating scale is needed for ERS components (charging units, power cables, communication systems, etc.) to determine the state of the new assets at any time.
4. Evaluate Alternatives: HERS-ST is a Transportation Economic Analysis Model that helps the user. The model would be modified to accommodate the improvements from ERS.
5. Project Prioritization and Selection: With the inclusion of ERS, the analyses would help determine the optimal locations for embedment, maintenance schedules, and available funding.
6. Project Implementation: This step would stay similar to the original TAM framework.
7. Performance Monitoring: Performance monitoring systems and schedules would need to be created for the ERS components.
8. Budget Allocation: This step would stay similar to the original TAM framework.

Figure 7 outlines the early framework for incorporating ERS into TAM. The Excel-based models for the baseline and ERS cases account for steps 2-4 in the TAM process: asset inventory, asset condition, and evaluate alternatives. From the literature review, the key considerations of TAM are risk, performance, and life-cycle planning. After assessing the HERS models, it was selected as the foundation for the Excel-based TAM models for this research. By using the HPMS database as an input, the asset inventory step is conducted. Next, HERS evaluates asset condition by looking for deficiencies in a road section. The deficiencies are based on pavement condition, surface type, volume/capacity ratio, lane width, right shoulder width, shoulder type, horizontal alignment, and vertical alignment. Finally, the overall HERS analysis accounts for the evaluation of alternatives step in the TAM process. Once the asset condition is determined, if a section is deficient, HERS will suggest methods to improve the condition. HERS then evaluates each alternative improvement by determining the benefits and costs of each suggested scenario. The evaluation and selection of the project may be based on the BCR, the constraints on funding, or a target performance level.

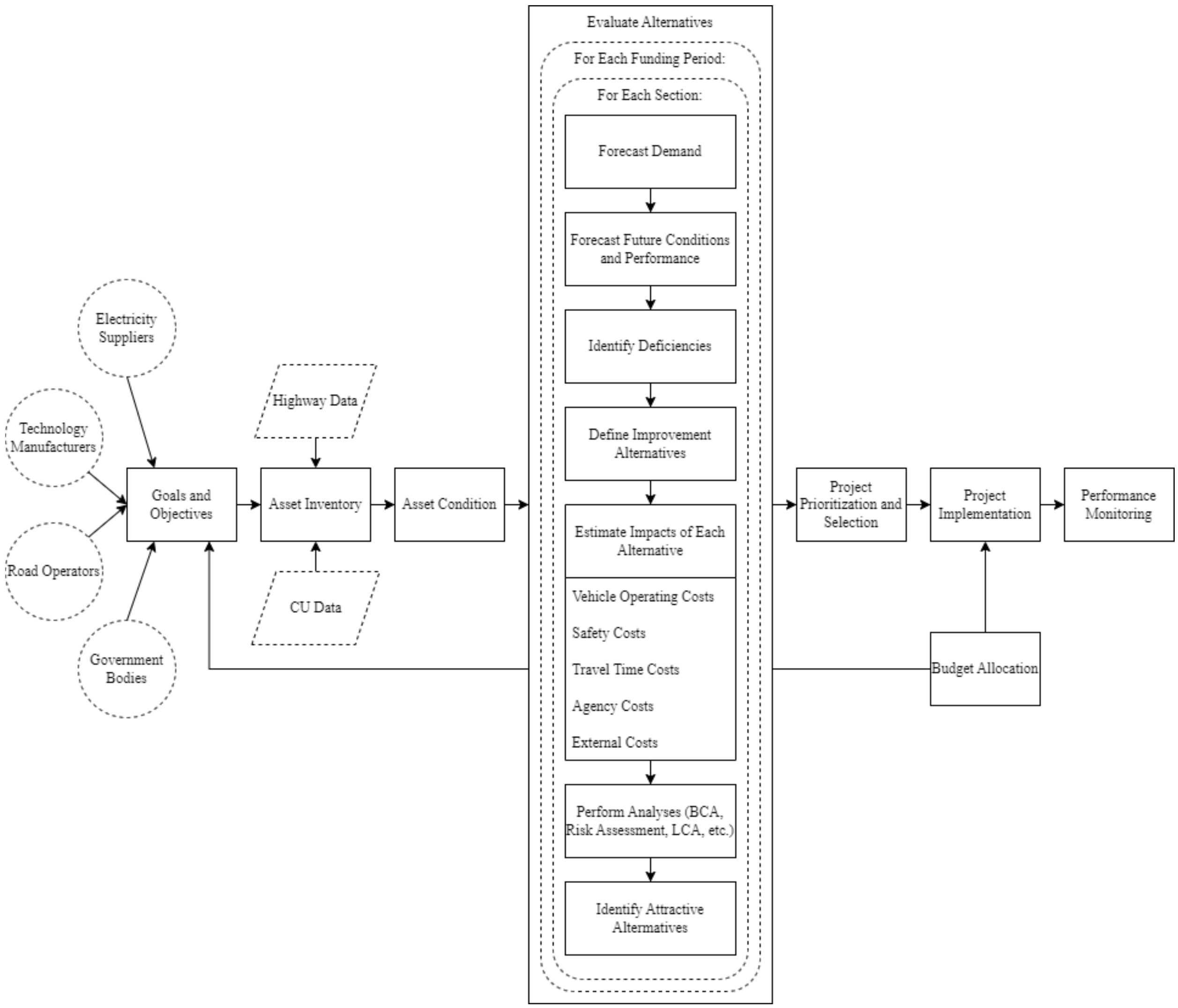

Figure 7 – Framework for incorporating ERS into TAM

3.1 Scope of Excel-based Models

Because HERS is broad in scope, it was necessary to narrow the extent of the Baseline and ERS Model analyses. Table 4 discusses the differences between the HERS model and the models developed for this research and a brief justification of the modifications. Narrowing the scope of the models allows for a preliminary analysis of the costs and benefits of ERS. However, these modifications posed limitations to the analysis. By making these changes from the original HERS process, it was difficult to validate the Baseline

Model results with the HERS results. These limitations will be further discussed in the next section as the development of the models is outlined.

Table 4 – Comparison of HERS and Excel Models

Category	HERS	Excel-based Models	Justification
No. of Sections as an Input	Unlimited	1000 (can be modified)	Limit data analyzed in Excel
Errors	Flags errors in input for the user to examine	Automatically corrects errors based on predetermined assumptions	Simplifies process for users
Analysis Types	Minimum BCR, Constrained Performance, and Constrained Funds	Minimum BCR	Goal of thesis
Functional Classes	9	1 – Urban Interstate	DWPT ERS function well on interstates
Improvements	28	2 – Resurfacing and reconstruction	Narrow scope of research
Vehicle Classes	All	Passenger Cars	Data on passenger EVs is more available than other vehicle classes

3.2 Creating the Baseline Model

To create the Baseline Model, the HERS Technical Report was closely followed. The model in Excel has tabs divided by the following categories:

- Red: Inputs
- Blue: Calculations and/or Analysis
- Green: Outputs
- Gray: Reference

3.2.1 Inputs

To begin developing the Baseline Model, a dataset was needed. For purposes of the scope of this work, a 2019 Texas HPMS dataset was used. The dataset was then reduced to just the Interstate 10 (I-10) in El Paso, Texas. This road section was still too large for the narrowed scope, so the final dataset consisted of 103 road sections spanning approximately six miles along downtown El Paso. These road sections consist of the highest annual average daily traffic (AADT) in the city for I-10.

HERS allows users to upload either an Excel or GIS-based HPMS dataset, which populates the data parameters in a specific order. The Baseline Model is limited to Excel and the data parameters must be in the specific order shown on the input tab or the analysis will not work. The Baseline Model directs the user to paste the dataset into the sheet in the specified order. The order is based on the 2019 Texas HPMS dataset used for this research.

3.2.2 Calculations

The Baseline Model then takes the dataset pasted into the sheet by the user and corrects any "errors" in the input. For this research, the errors are numbers of zero in sections where a zero would not make sense. For example, if the section shows there are 10 through lanes but zero peak and counter-peak lanes, this would be classified as an error in the file. The "Edited Data" tab in the model then assumes that since there are 10 through lanes, then the number of peak and counter-peak lanes would each be half of that number, therefore, 5 lanes each. If the number of through lanes is an odd number, then the peak lanes would get the higher number of lanes when divided. This type of correction is done for many of the other data parameters based on assumptions which were needed to correct as many zeros or empty data fields as possible and run calculations in the Baseline Model. Figure 8 shows the basic process of how the errors are identified and corrected. The data parameters chosen to correct are specific to the 2019 HPMS dataset used, however, the corrections would work for any other dataset.

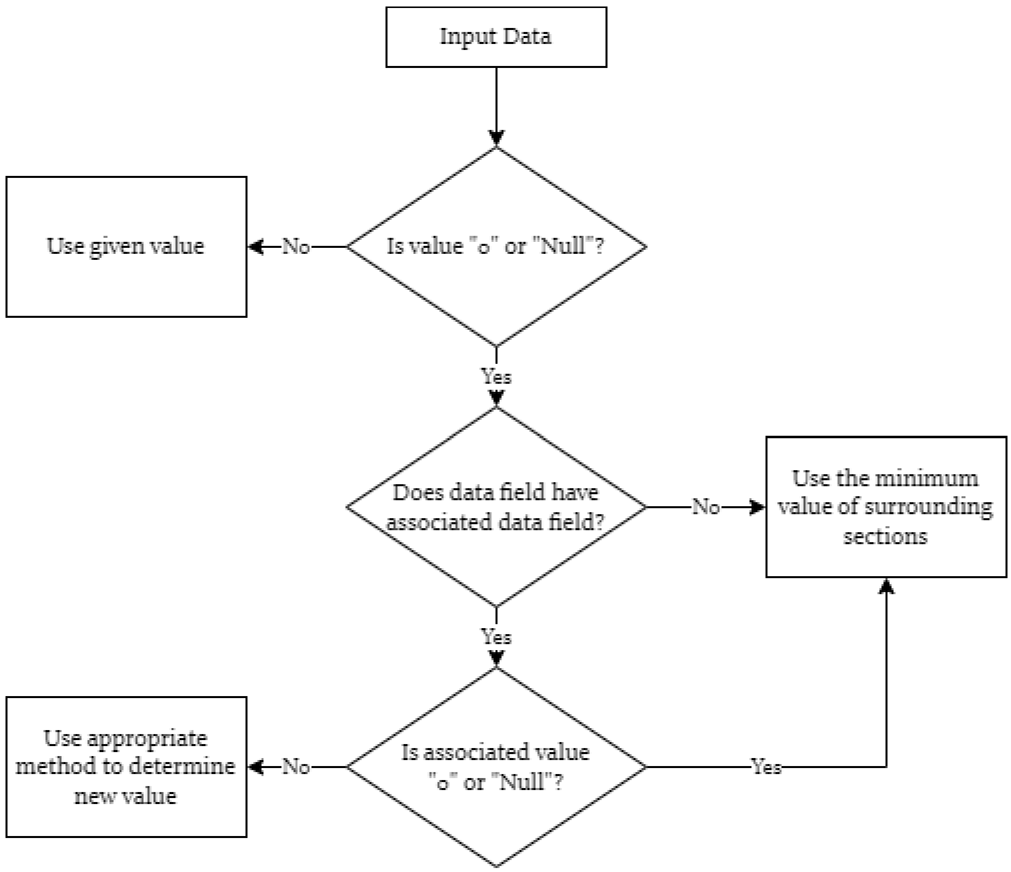

Figure 8 – Process for updating HPMS input data in Excel-based models

Once the inputs were addressed and any "errors" were corrected, the model then makes calculations based on the HERS Technical Report. This involves determining the structural number or depth, capacity, and traffic growth rate for each section. These equations were closely followed and can be referenced in the HERS Technical Report

Chapter 3 (FHWA, 2014). These values are then used for the analysis of the BCR for the output sections.

For the BCR, the cost is the capital cost of the improvement, and the benefits are the savings in travel time, operating, emissions, and maintenance costs of the improvement compared to an alternative "do-nothing" scenario. These costs and benefits were calculated following the process outlined in the HERS Technical Report Chapter 5 (FHWA, 2014). The only changes made were simplifying the equations by using only the urban interstate and passenger vehicle-associated values. Figure 9 shows a screenshot of a section of the Calculations tab in the Baseline Model.

CALCULATIONS

No.	AESALS									Conversions	Structural Number	
	LANFAC	Pavement Group	System	System Type	$EALFAC_{SU}$	$EALFAC_{CM}$	SU	CM	SU+CM	IRI to PSR	AESALS	SNORD
1	0.6	Rigid	Urban	4	0.85	3.71	0.16	0.22	0.38	2.56	12714372.51	10.31
2	0.6	Rigid	Urban	4	0.85	3.71	0.16	0.22	0.38	2.56	15521075.79	10.39
3	0.6	Rigid	Urban	4	0.85	3.71	0.16	0.22	0.38	2.56	15521075.79	10.39
4	0.6	Rigid	Urban	4	0.85	3.71	0.16	0.22	0.38	3.05	15521075.79	10.39

Figure 9 – Screenshot of Calculations tab in Baseline Model

3.2.3 Outputs

The HERS Model outputs are completely customizable to the user's preference. After conducting several case studies in HERS and determining the most appropriate outputs for the narrowed-scope Excel-based models, the output parameters to be used were selected. For the goals of this research, the most important factors to display to the user are deficiency criteria, recommended improvement, and costs of that improvement for each section. Figure 10 shows a screenshot of the output page of the Baseline Model.

Funding Period 1

No.	Deficiency Criteria			Recommended Improvement			Selected Improvement			Costs				
	Pavement Condition		Surface Type	Type	Lanes Added	Capacity Increase	Type Selected	B/C Ratio	Cost ($k)	Improvement ($k)	User		External	Agency
	PSR	IRI									Travel Time	Operating	Emission	Maintenance
1	Fair	Fair	Good	Resurface	None	None	Resurface	2.8614	878	509	262	595	143	457
2	Fair	Fair	Good	Resurface	None	None	Resurface	165.9611	878	9	262	595	143	457
3	Fair	Fair	Good	Resurface	None	None	Resurface	9.2201	878	158	262	595	143	457

Figure 10 – Screenshot of output for Funding Period 1 of Baseline Model

3.2.4 Limitations of Baseline Model

The Baseline Model was developed to understand the HERS process and the theory/equations behind it. However, the HERS model was closed source, so the exact source code was unavailable and described in the HERS Technical Report. The HERS model also had a much larger scope than necessary for this preliminary research on TAM for ERS. With that, many modifications had to be made to develop the Baseline Model. The Baseline Model only analyzes projects on an urban interstate and only accounts for passenger vehicles traveling on the road section. In a realistic project, all vehicles are necessary to accurately project future traffic growth and pavement condition. Also, the model only accounts for surface pavement condition deficiencies and makes an analysis to correct deficiencies by either resurfacing or reconstructing completely. Finally, with the modifications made, it was difficult to validate the results from the Baseline Model with the results from the HERS model. The Baseline Model only outputs the BCR for one improvement type based on the narrowed scope. The HERS model analyzes several combinations of improvement scenarios and compares the BCR from each project to suggest an improvement. The results from the models most likely differ for the following reasons:

1. The HERS model analyzes scenarios using nine different vehicle classes while the Baseline Model only analyzes based on passenger vehicles.
2. The Baseline Model does not allow for values of "0" or "Null" and corrects those values. The HERS model allows the user to either change the value or override the errors.
3. The data values used for the costs and benefits of the HERS model are predetermined and some of the values were not included in the HERS Technical Report.
4. The HERS model makes an analysis in the middle of a funding period while the Baseline model analyzes the scenarios at the beginning of the funding period.

Although the outputs differ for the HERS and Baseline models, it is important to note that HERS is only used as a foundation for creating a TAM framework for ERS. The process of determining the BCR for HERS was of most interest and was adapted to meet the needs of this research. Since the process was closely followed and the Baseline Model output credible results, the model was deemed valid.

3.3 Creating the ERS Model

The Baseline and ERS models are similar in process and aesthetics. The Baseline Model was developed to determine how the process needs to be modified to incorporate ERS components. The components needed to be modified are associated with the charging infrastructure and the EVs. Because this thesis focuses on developing a preliminary framework, the modifications are broad and general in scope. The values in the Baseline Model are replaced by the values for the ERS Model. If the Baseline Model does not include a certain value, then it is simply added as an improvement to the road. For example, the

Baseline Model does not include charging infrastructure, so the charging infrastructure is considered an improvement. When this improvement is selected, it is in conjunction with the reconstruction improvement, as this model as a framework only accounts for initial projects.

The ERS data is based on a DWPT system modeled in a high-density traffic corridor in California, which can be seen in Figure 11 (Trinko et al., 2022). The analysis includes cost components for "1st-of-a-kind" and "nth-of-a-kind" cases. For the scope of this work, the ERS data used is taken from the 1st-of-a-kind case, which considers electronic components embedded in pre-cast Portland Cement Concrete (PCC) slabs. The construction of the ERS involves removing the full width of the existing lane and installing the PCC slabs with the CU on site. The total cost of this case is $6.51 M/lane-km. This includes the cost for the CU, pavement removal, electrical, and signage, as well as indirect, soft, and contingency costs. The significant costs used in the ERS Model are as follows (Trinko et al., 2022):

1. Cost of electronics: $2.00 M/lane-km
2. Total cost of 1st-of-a-kind case: $6.51 M/lane-km
3. Fueling cost for light-duty vehicles: $0.019/km for electric power
4. Operating cost for light-duty electric vehicles: $0.129/km

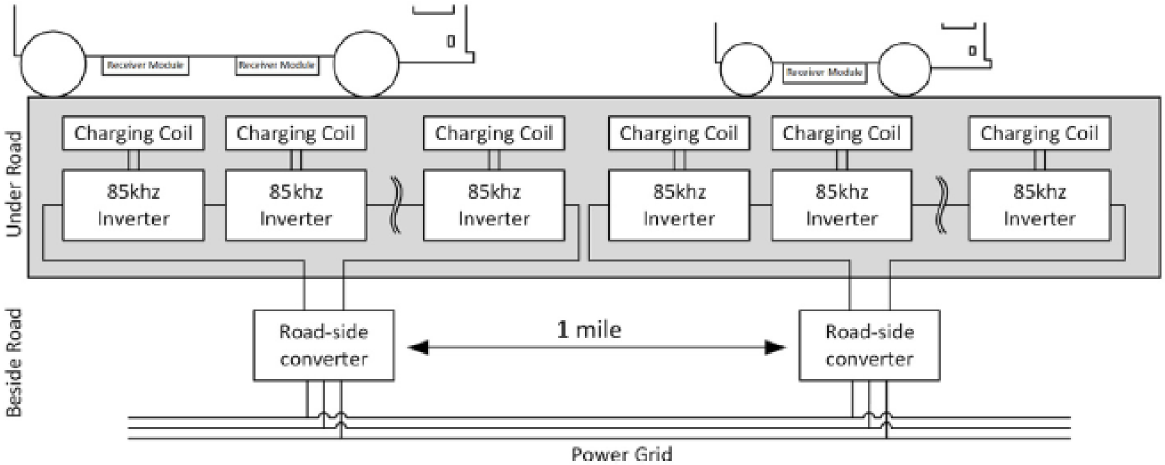

Figure 11 – Overview of DWPT system used in the analysis (Trinko et al., 2022)

3.3.1 Limitations of ERS Model

As ERS is a relatively new concept, the data associated with it is limited, especially considering economic analyses. Due to this limitation, maintenance costs of the CU and EV were not considered. The analysis by Trinko et al. (2022) considers all traffic mixes, however, the scope of this work is narrowed to passenger vehicles. The ERS Model developed for this research acts as a basic framework for incorporating new assets into the TAM process. The values used to represent ERS in this work are high-level but can be modified as data becomes more accessible and accurate.

CHAPTER 4: CASE STUDY ANALYSES

This chapter describes the case studies for the HERS-ST and Excel-based TAM models. The HERS-ST case study was conducted to understand the model and the important factors in the optimization analyses developed by the FHWA.

4.1 Goals and Objectives

The first step in the TAM process is to clearly identify the goals and objectives of the plan to preserve the assets. Since ERS has many key players, each of their goals and objectives must align to effectively maintain both the roads and charging components. Figure 11 outlines the stakeholders, TAM goals, ERS assets, and TAM objectives identified for this research. The goals and objectives are general, as performance measures for ERS vary based on CU type, manufacturer, and location, among other factors.

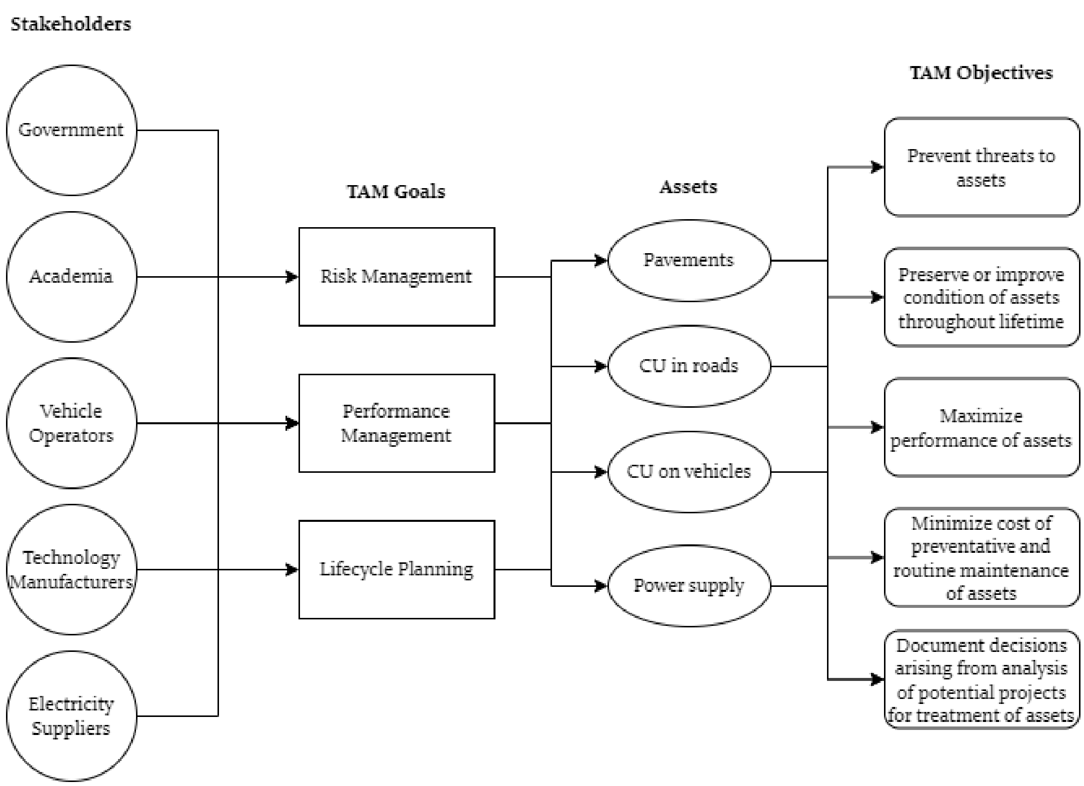

Figure 12 – Goals and objectives for key stakeholders in ERS

4.2 Asset Inventory

The dataset, located in I-10 downtown El Paso, Texas, spans roughly six miles with AADTs greater than 170,000. This is the highest AADT in the region and was chosen based on the assumption that pavement deterioration will occur quicker in this area. The surface type of the pavement in this area is classified as continuously reinforced concrete pavement (CRCP) and results in cracking over time. Based on the information given in the HPMS dataset, the assets underwent major construction in the 1960s, while the last improvements were made in the 1990s. The dataset used for each of the case studies is shown Figure 12 and described in Table 6.

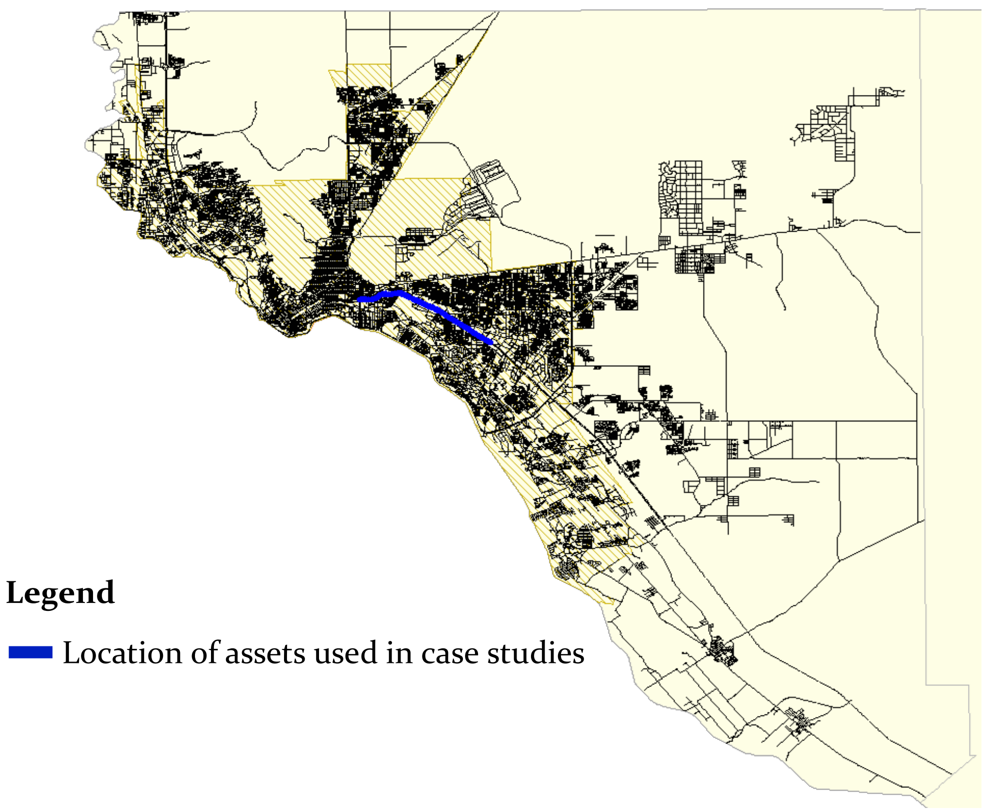

Figure 13 – Map locating assets in dataset

Table 6 – Description of Dataset Used in Case Studies

Parameter	Description
Number of Items	103
Year Recorded	2019
State Code	48
Route Identifier	IH0010-KG
Begin Point	19.374
End Point	25.603
Length (miles)	6.229
Functional System	1 – Interstate
Facility Type	2 – Two-Way Roadway
Speed Limit (mph)	60
AADT	181,236
Surface Type	5 – Continuously Reinforced Concrete Pavement (CRCP)

4.3 Asset Condition

The asset condition is largely determined by the International Roughness Index (IRI) or the Present Serviceability Rating (PSR). IRI, the standard HPMS roughness indicator, acts as an objective measure of pavement condition and is consistent in measurement technique across all states. PSR is more subjective and can be determined in various ways depending on the state. The IRI from the HPMS dataset needed to be converted to PSR to be used by the HERS process.

The average IRI of the dataset ranged from 95-170, resulting in approximately 73% of road sections being classified as fair condition. 18% of the road sections were in poor condition and only 9% were in good condition.

Table 5 – Summary of pavement condition of assets used in the dataset

IRI Range	Condition	Percentage of Sections (%)
<95	Good	9
95-170	Fair	73
>170	Poor	18

4.4 Evaluate Alternatives

The evaluation of alternatives stage is carried out using economic and engineering analyses. This consists of using a pavement deterioration model, travel forecast model, speed model, and evaluation of improvements. The process for each of these steps is detailed in the HERS Technical Report and was followed closely for the creation of the Baseline and ERS Models. The results from this stage vary between the HERS, Baseline, and ERS Models.

4.4.1 HERS Model

The HERS case study uses the following methods to conduct analyses:

1. Widening Feasibility Model: Determine potential to increase within the road section.
2. Capacity Model: Determine current capacity and capacity needed to accommodate growth in traffic volume.
3. Pavement Deterioration Model: Determine effects of traffic on PSR and forecast pavement condition.
4. Estimation of Operating and Safety Costs
5. HERS Speed Model: Determine travel time costs, emissions costs, and vehicle operating costs.
6. Travel Forecast Model: Determines baseline conditions and predicts future travel along the road section.

7. Estimation of Agency Costs and Benefits: Determines reduction in the cost of routine maintenance and cost of next improvement resulting from prioritizing improvement at specific period in time.
8. Evaluation of Improvements: Determines capital cost of improvements, residual value, and BCR.

The analysis provides various outputs, however, for the scope of this work, the improvement cost and BCR were of most interest. A basic summary of results can be seen in Table 6 and Figure 14. The figure depicts the location of the segments described in Table 6. The corresponding table shows the improvement recommended by HERS for the funding period, the capital cost of the improvements, the BCR, and initial versus final IRI. The results obtained from this case study are used as a foundation to compare the results from the Baseline and ERS Models with.

Table 6 – Summary of results from HERS Case Study

Segment	Recommended Improvement	Improvement Cost ($k)	BCR	Initial/Final IRI
1	Resurfacing	610	2.01	145/100
2	Resurfacing	550	2.56	155/100
3	Resurfacing-Shoulder Improvements	560	1.92	152/98

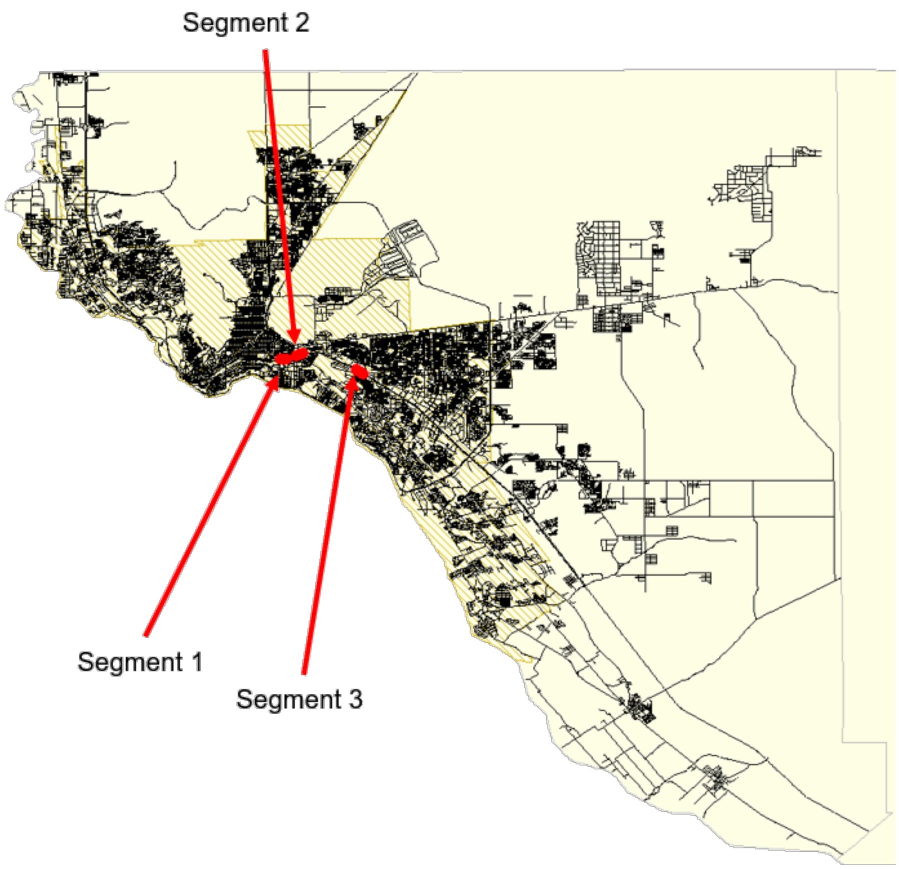

Figure 14 – Road sections selected by HERS for improvement

4.4.2 Baseline Model

The Baseline Model conducts an analysis as a high-level, simplified version of the HERS methodology. The model determines traffic growth rates, pavement deterioration, user, external, and agency costs. A summary of the results from the Baseline Model Case Study is shown in Table 7. The segments chosen for the summary are representative of the segments chosen by HERS in the HERS Case Study. The costs and BCR are similar, but not exact, due to the extent of the analysis for the Excel-based models.

Table 7 – Summary of results from Baseline Model Case Study

Segment	Pavement Condition	Improvement	Improvement Cost ($k)	BCR
1	Fair	Resurface	509	2.86
2	Fair	Resurface	579	2.50
3	Fair	Resurface	509	2.84

4.4.3 ERS Model

The ERS Model is like the HERS and Baseline Models, however, the pavement deterioration will not trigger an improvement such as constructing ERS. For the scope of the analysis, if the model recommends an improvement on the road section, it assumes that the optimal time to embed in the road is when the maintenance of the existing road occurs. The model then incorporates the base values discussed in section 3.3 – Creating the ERS Model. However, both the HERS Model and Baseline Model, which is a very simplified version of the HERS Model, uses parameters not yet available for ERS, making the results for the ERS Model extremely skewed. For example, all the BCRs resulting from the analysis are greater than 100. The BCR for the ERS only considers the capital cost of constructing the ERS and a slight modification in the operating cost equation, rendering the results as not valid. For the purposes of developing a framework, the model still uses the original Baseline Model values to calculate the results, however, these values can be easily adapted as ERS data becomes more readily available.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

As the transportation industry moves toward a sustainable future, new technologies arise in efforts to reach zero emissions. With new technologies come new assets, making it important for diverse industries and stakeholders to engage with one another for the same goals. Within the transportation industry, TAM makes the decision-making process cohesive and efficient. TAM prioritizes minimizing risk and optimizing performance throughout the entire lifecycle of the assets, while considering cost-efficiency. Because of this, it is important to incorporate new assets into the existing TAM framework, streamlining the decision-making process relative to new assets.

This research takes the existing TAM framework and aims to assess sustainable transportation solutions with it. The HERS and Baseline Models produced results that can be used to make data-backed decisions as a TAM practitioner. The Baseline Model for TAM can be easily modified to incorporate new assets, thus creating the ERS Model. However, using HERS as a foundation for the Baseline and ERS Models produced vast limitations. The existing BCA methods for the models need data not readily available for ERS, as the technology is new in the industry. There lacks significant research on the maintenance for ERS throughout the asset lifecycle, but with the framework developed for this thesis, the next steps for uniting various stakeholders into the transportation decision-making process is easier.

Because this work produced a preliminary framework for TAM for ERS, it is recommended that future work expands on the ERS Model. Future work should consider not only passenger vehicles, but medium- and heavy-duty vehicles as well. Future TAM models for ERS should also utilize more accurate data for user, safety, maintenance, operating, and external costs to produce valid results for the BCR for constructing ERS. It is also recommended that the ERS Model incorporates a risk analysis into the model.

The framework developed for this thesis provides a pathway for new assets to be incorporated into the existing TAM methodology. By using HERS, a model developed by the FHWA, as a foundation, the Baseline and ERS Models can be easily adapted into the transportation industry. Developing a TAM framework for ERS eliminates barriers that may arise in the transportation decision-making process throughout the lifecycle of new assets, catalyzing a sustainable future for all.

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APPENDIX A: Transportation Asset Management in 23 U.S. Code § 119

From 23 U.S. Code § 119:

(e) State Performance Management. -

(1) In general. -A State shall develop a risk-based asset management plan for the National Highway System to improve or preserve the condition of the assets and the performance of the system.

(2) Performance driven plan. -A State asset management plan shall include strategies leading to a program of projects that would make progress toward achievement of the State targets for asset condition and performance of the National Highway System in accordance with section 150(d) and supporting the progress toward the achievement of the national goals identified in section 150(b).

(3) Scope. -In developing a risk-based asset management plan, the Secretary shall encourage States to include all infrastructure assets within the right-of-way corridor in such plan.

(4) Plan contents. -A State asset management plan shall, at a minimum, be in a form that the Secretary determines to be appropriate and include-

(A) a summary listing of the pavement and bridge assets on the National Highway System in the State, including a description of the condition of those assets;

(B) asset management objectives and measures;

(C) performance gap identification;

(D) lifecycle cost and risk management analyses, both of which shall take into consideration extreme weather and resilience;

(E) a financial plan; and

(F) investment strategies.

(5) Requirement for plan. -

(A) In general. -Notwithstanding section 120, each fiscal year, if the Secretary determines that a State has not developed and implemented a State asset management plan consistent with this section, the Federal share payable on account of any project or activity for which funds are obligated by the State in that fiscal year under this section shall be 65 percent.

(B) Determination. -The Secretary shall make the determination under subparagraph (A) for a fiscal year not later than the day before the beginning of such fiscal year.

(6) Certification of plan development process. -

(A) In general. -Not later than 90 days after the date on which a State submits a request for approval of the process used by the State to develop the State asset management plan for the National Highway System, the Secretary shall-

(i) review the process; and

(ii)(I) certify that the process meets the requirements established by the Secretary; or

(II) deny certification and specify actions necessary for the State to take to correct deficiencies in the State process.

(B) Recertification. -Not less frequently than once every 4 years, the Secretary shall review and recertify that the process used by a State to develop and maintain the State asset management plan for the National Highway System meets the requirements for the process, as established by the Secretary.

(C) Opportunity to cure. -If the Secretary denies certification under subparagraph (A), the Secretary shall provide the State with-

(i) not less than 90 days to cure the deficiencies of the plan, during which time period all penalties and other legal impacts of a denial of certification shall be stayed; and

(ii) a written statement of the specific actions the Secretary determines to be necessary for the State to cure the plan.

(7) Performance achievement. -A State that does not achieve or make significant progress toward achieving the targets of the State for performance measures described in section 150(d) for the National Highway System shall include as part of the performance target report under section 150(e) a description of the actions the State will undertake to achieve the targets.

(8) Process. -Not later than 18 months after the date of enactment of the MAP–21, the Secretary shall, by regulation and in consultation with State departments of transportation, establish the process to develop the State asset management plan described in paragraph (1).

APPENDIX B: Highway Performance Monitoring System Parameters

Field	Description	Category
Year_Record	The calendar year for which the data are being reported.	Identification
State_Code	The State Federal Information Processing Standard (FIPS) code.	Identification
Route_ID	The unique identifier for a given roadway (i.e., route).	Identification
Begin_Point	The point of origin for a given section of road.	Identification
End_Point	The terminus point for a given section of road.	Identification
Section_Length	The true length (i.e., measured length) for a given section of road.)	Identification
F_System	The FHWA approved Functional Classification System.	Inventory
Urban_Code	The U.S. Census Urban Area Code.	Inventory
Facility_Type	The operational characteristic of the roadway.	Inventory
Structure_Type	Roadway section that is a bridge, tunnel or causeway.	Inventory
Access_Control	The degree of access control for a given section of road.	Inventory
Ownership	The entity that has legal ownership of a roadway.	Inventory
Through_Lanes	The number of lanes designated for through-traffic.	Inventory
HOV_Type	The type of managed lane operations (e.g., HOV, HOT, ETL, etc.).	Inventory
HOV_Lanes	Maximum number of lanes in both directions designated for managed lane operations.	Inventory
Peak_Lanes	The number of lanes in the peak direction of flow during the peak period.	Inventory
Counter_Peak_Lanes	The number of lanes in the counter-peak direction of flow during the peak period.	Inventory

Turn_Lanes_R	The presence of right turn lanes at a typical intersection.	Inventory
Turn_Lanes_L	The presence of left turn lanes at a typical intersection.	Inventory
Speed_Limit	The posted speed limit.	Inventory
Toll_Charged	Identifies sections that are toll facilities regardless of whether or not a toll is charged.	Inventory
Toll_Type	Indicates the presence of special tolls (i.e., High Occupancy Toll (HOT) lane(s) or other managed lanes).	Inventory
Route_Number	The signed route number.	Route
Route_Signing	The type of route signing.	Route
Route_Qualifier	The route signing descriptive qualifier.	Route
Alternative_Route_Name	A familiar, non-numeric designation for a route.	Route
AADT	Annual Average Daily Traffic.	Traffic
AADT_Single_Unit	Annual Average Daily Traffic for single-unit trucks and buses.	Traffic
Pct_Peak_Single	Peak hour single-unit truck and bus volume as a percentage of total AADT.	Traffic
AADT_Combination	Annual Average Daily Traffic for Combination Trucks.	Traffic
Pct_Peak_Combination	Peak hour combination truck volume as a percentage of total AADT.	Traffic
K_Factor	The design hour volume (30th largest hourly volume for a given calendar year) as a percentage of AADT.	Traffic
Dir_Factor	The percent of design hour volume (30th largest hourly volume for a given calendar year) flowing in the higher volume direction.	Traffic
Future_AADT	Forecasted AADT.	Traffic
Signal_Type	The predominant type of signal system on a sample section.	Traffic
Pct_Green_Time	The percent of green time allocated for through-traffic at intersections.	Traffic

Number_Signals	A count of at-grade intersections where traffic signals are present.	Traffic
Stop_Signs	A count of at-grade intersections where stop signs are present.	Traffic
At-Grade_Other	A count of at-grade intersections, where full sequence traffic signal or stop sign traffic control devices are not present, in the inventory direction.	Traffic
Lane_Width	The measure of existing lane width.	Geometric
Median_Type	The type of median.	Geometric
Median_Width	The existing median width.	Geometric
Shoulder_Type	The type of shoulder.	Geometric
Shoulder_Width_R	The existing right shoulder width.	Geometric
Shoulder_Width_L	The existing left shoulder width.	Geometric
Peak_Parking	Specific information about the presence of parking during the peak period.	Geometric
Widening_Obstacle	Obstacles that prevent widening of the existing roadway for additional through lanes.	Geometric
Widening_Potential	The number of through lanes that could be potentially added.	Geometric
Curves_A-F	Curve classification data.	Geometric
Terrain_Type	The type of terrain.	Geometric
Grades_A-F	Grade classification data.	Geometric
Pct_Pass_Sight	The percent of a Sample Panel section meeting the sight distance requirement for passing.	Geometric
IRI	IRI is the road roughness index most commonly used worldwide for evaluating and managing road systems. Road roughness is the primary indicator of the utility of a highway network to road users. IRI is defined as a statistic used to estimate the amount of roughness in a measured longitudinal profile.	Pavement
PSR	Present Serviceability Rating (PSR) for pavement condition.	Pavement

Surface_Type	Surface type on a given section.	Pavement
Rutting	Average depth of rutting. A rut is defined as longitudinal surface depressions in the asphalt pavement derived from measurements of a profile transverse to the path of travel on a highway lane. It may have associated transverse displacement. Asphalt pavement (Item 49 codes '2', '6', '7', and '8') is defined as pavements where the top-most surface is constructed with asphalt materials.	Pavement
Faulting	Faulting is defined as a vertical misalignment of pavement joints in Portland Cement Concrete Pavements (Jointed Concrete Pavement). Jointed Concrete Pavements is defined as pavements where the top-most surface is constructed of Portland cement concrete with joints (Item 49 codes '3', '4', '9', '10', and '11'). It may be constructed of either reinforced or unreinforced (plain) concrete.	Pavement
Cracking_Percent	Cracking is defined as a fissure or discontinuity of the pavement surface not necessarily extending through the entire thickness of the pavement.	Pavement
Year_Last_Improv	The year in which the roadway surface was last improved.	Pavement
Year_Last_Construction	The year in which the roadway was constructed or reconstructed.	Pavement
Last_Overlay_Thickness	Thickness of the most recent pavement overlay.	Pavement
Thickness_Rigid	Thickness of rigid pavement.	Pavement
Thickness_Flexible	Thickness of the flexible pavement.	Pavement
Base_Type	The base pavement type.	Pavement
Base_Thickness	The thickness of the base pavement.	Pavement
Climate_Zone	Climate zone as defined by the 4 LTPP climate zone descriptions.	Pavement

Soil_Type	Climate zone as defined by the 4 LTPP climate zone descriptions.	Pavement
County_Code	The County Federal Information Processing Standard (FIPS) code.	Inventory
NHS	A Roadway that is a component of the National Highway System (NHS).	Special Networks
STRAHNET_Type	A Roadway that is a component of the National Highway System (NHS).	Special Networks
Truck	Roadway section that is a component of the National Truck Network (NN) as defined by 23 CFR 658.	Special Networks
Future_Facility	Roadway section that is a component of the National Truck Network (NN) as defined by 23 CFR 658.	Special Networks
Maintenance_Operations	The legal entity that maintains and operates a roadway.	Inventory
Capacity	The legal entity that maintains and operates a roadway.	Traffic
Dir_Through_Lanes	The legal entity that maintains and operates a roadway.	Inventory

VITA

Kamalen Maria Santos Diaz was born on a small island called Guam. She moved to El Paso, Texas when she was three, and due to the military, lived in New York and Virginia during high school. She received her Bachelor of Science in Civil Engineering from the University of Texas at El Paso in the year 2020. In January of 2021, she began pursuing her Master of Science degree in Civil Engineering (M.S.C.E). She joined the National Science Foundation (NSF) Engineering Research Center (ERC) on "Advancing Sustainability for Powered Infrastructure for Electric Roadways" (ASPIRE) within the UTEP CE department and began research under the direct supervision of her thesis advisor, Dr. Adeeba A. Raheem an UTEP ASPIRE center Director, Dr. Soheil Nazarian, who both provided guidance on developing a transportation asset management framework for electrified transportation systems. She attended the 2021 Transportation Research Board Annual Meeting as a Minority Student Fellow, where she developed here skills in research, public speaking, and technical writing. Ms. Diaz also served as the ASPIRE Student Leadership Council Co-Chair for 2022 and is expected to pursue a career in transportation engineering in the industry upon graduation.