Life Cycle Cost Analysis of Vehicle Detection Technologies and their Impact on Adaptive Traffic Control Systems

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INTRODUCTION

Transportation agencies are adopting and installing adaptive signal control technologies (ASCT) to advance the operational performance of their coordinated corridors and networks. ASCTs use real-time traffic data to optimize signal timing plans such as cycle lengths, splits, and offsets. Their goal is to minimize traffic delays and stops, and increase traffic flow. Recently ASCTs have become popular in the United States and many agencies have been installing these systems on congested corridors. These adaptive/responsive systems require high resolution data that is measured by the detection systems installed throughout the network (1). Non-invasive vehicle detection, such as video or radar detection which is not placed in the pavement, is easier to install and typically promoted as less economically detrimental. Even though in-pavement vehicle detection typically provides the most accurate high resolution data, agencies opt to install or utilize existing non-invasive detection because of ease of installation and lack of negative impact on pavement. The associated amount of error accompanying non-invasive detection strategies may offset any benefits associated with installing adaptive/responsive signal control strategies.

This research presents a life cycle cost analysis (LCCA) of vehicle detection technologies and their impact on adaptive signal control strategies. This information can be conveyed to transportation agencies and provide recommendations toward installing adaptive/responsive signal control and vehicle detection. This paper focuses on a LCCA of four adaptive signal control technologies and seven types of vehicle detection technologies. Within this paper is a discussion of previous work pertaining to the current research, explanation of the LCCA tool (LCCAT), the experimental design, and a discussion of the results and implications.

BACKGROUND

In recent years, several researchers have undertaken life cycle cost analyses in relation to transportation. One paper presents the findings from an evaluation and economic analysis of the literature on benefit-cost estimates of public transit systems in the United States (2). Some of the key benefits found in this study include decreased traffic congestion, economic stimulus and job prosperity, money savings for individuals, air quality enhancement, and reduced traffic fatalities (2). In the report published by the National Cooperative Highway Research Program (NCHRP) *Estimating the Life-Cycle Cost of Intersection Designs*, researchers developed a spreadsheet-based tool that can be used by a practitioner to compare the life-cycle costs of alternative designs for new and existing intersections (3)

One report evaluated the Virginia Department of Transportation's Adaptive Signal Control Technology pilot project. Researchers computed a benefit-cost ratio for each adaptive signal control site to assess whether the deployment produced an overall net benefit (4). The Virginia Department of Transportation Traffic Engineering Division provided the researchers with costs associated with the initial purchase and installation of an adaptive signal control system. (4). This study did not include ongoing maintenance costs supplementary to system deployment as the researchers claimed the data could not be easily isolated. Researchers from the University of Washington presented criteria for the selection and application of advanced traffic signal systems. This report addresses performance measurement and selection for adaptive signal control system installation (5). The Excel-based implementation of selection is intended to be as straight-forward as possible and does not indicate any life cycle cost changes due to varying detection selection for running the adaptive system.

One study focused on the long-term benefits of adaptive traffic control under varying traffic flows during weekday peak hours (6). The final results showed that the Sydney Coordinated Adaptive Traffic System (SCATS) outperformed existing time of day signal-timing plans by about 20% (6). In another project, *Evaluation of Vehicle Detection Technologies for Applications in Georgia,* researchers identified the circumstances appropriate for different detection technologies in adaptive signal control technologies. An agency survey was conducted through the Georgia Department of Transportation (GDOT) to assess nontechnical performance criteria such as life cycle cost and ease of installation and maintenance. They used the survey results to construct a multi-criterion framework to evaluate vehicle detection technologies using technical and nontechnical performance criteria (7). The researchers propose specific guidelines for adaptive systems and their corresponding vehicle detection. This report provides their results in a multicriteria evaluation which results in weights to compare detection. No connection was made between specific ASCT technologies and deployment of the identified detection types.

According to the Federal Highway Administration (FHWA), the selection process that is suggested when determining if an ASCT is appropriate, and which system should be chosen, requires an examination of life-cycle issues including operations and maintenance costs (8). However, previous studies only included ASCTs that had sufficient data for comparison sake, and did not include systems that lacked data. The agency personnel strategies switch from a maintenance heavy focus to an operational focus (9). These projects did not present numerical results indicating the actual costs associated with long term operations and maintenance costs.

The research present in this paper builds upon the previous work in several ways. First, it considers not only initial deployment costs, but ongoing maintenance and operational costs throughout the life cycle of single control and vehicle detection technologies. Also, it shows the cost difference when a single adaptive system is subjected to multiple detection layouts. Signalized intersections depend on vehicle detection to operate the intersection and keep traffic flowing. As more transportation agencies begin to employ adaptive signal system technologies in their networks, the need to measure the costs and benefits associated with not only employing adaptive systems, but the decisions as to which vehicular detection should be selected for the system, becomes more pressing.

LIFE CYCLE COST ANALYSIS TOOL

The life cycle cost analysis tool (LCCAT) was developed using Microsoft Excel with the end goal of allowing a user to select and compare various signal control alternatives and their corresponding vehicle detection configuration. The tool allows for the selection of individual signal control and vehicle detection for all approaches for up to ten alternatives. The LCCAT evaluates alternatives on a net present basis and converts all future annual and replacement costs to present value. The LCCAT output provides a life cycle cost analysis summary of deployment costs and resulting equivalent user costs. This user friendly Workbook provides a comparison between ASCT technologies and different combinations of vehicle detection technologies. The LCCA analysis is based on initial purchase and installation cost, annual maintenance costs, and any replacement costs. Using a discount rate analysis, the tool compares all components of the alternative in terms of net present value.

The LCCAT provides two comparison measurements: life cycle cost of the alternative and user costs associated with the other alternatives. The life cycle analysis summary provides the user with the lowest life cycle cost, the highest life cycle costs, various components of the breakdown of life cycle costs, and visualizations of those costs. The user costs summary provides information on user time savings and reduction in crashes that the more expensive alternatives would need to overcome to be the preferred alternative. The associated calculations, broken down further in later sections, were established through the use of the AASTHO Red Book. This information encapsulates all the immediate and long term costs associated with the deployment of an ASCT system and vehicle detection by discounting those costs to the net present value in addition to providing the amount of additional user time savings and reduction in crashes the more expensive alternatives must provide to be considered as a preferred alternative.

EXPERIMENTAL DESIGN

The motivating factor behind the selection of technologies and comparison scenarios was preference of the Oregon Department of Transportation (ODOT), as they sponsored this research. The following section summarizes the technologies used and cost information gathered.

Adaptive Signal Control Technologies

ASCTs use real-time traffic data to optimize signal timing plans such as cycle lengths, splits, and offsets. Their goal is to minimize traffic delays and stops, and increase traffic flow. Recently ASCTs have become popular in the United States and many agencies have been installing these systems on congested corridors. This document particularly looks at four ASCT technologies deployed by ODOT:

- Sydney Coordinated Adaptive Traffic System (SCATS)
- Trafficware SynchroGreen
- Rhythm Engineering InSync: Fusion
- Northwest Signal (Peek) Transcend

Additionally, as a baseline measurement this research includes a coordinated signal option for comparisons.

Vehicle Detection Technologies

Vehicle detection has the ability to provide a traffic signal with various types of information including presence detection, vehicle occupancy, vehicle count, vehicle speed, and other metrics. Adaptive systems rely heavily on this information to make decisions that accommodate real-time traffic conditions. There are two primary types of vehicle detection: invasive detection (within the pavement) and non-invasive detection (located outside of the roadway surface). Invasive detection is typically cut into the pavement on a lane by lane basis and commonly uses inductive detection to detect the metal from vehicles. Non-invasive detection is typically mounted on existing infrastructure such as signal mast arms or luminary poles, and can be in the form of video detection, radar detection, infrared detection, or others. Cost information was procured for the following devices and are included in the analysis:

- Inductive Loop Stopbar
- Inductive Loop Advanced
- Sensys Magnetometers
- Wavetronix SmartSensor Matrix (radar)
- Wavetronix SmartSensor Advanced (radar)
- Iteris VersiCam (video)
- Iteris Vantage Vector (hybrid radar and video)
- Traficon FLIR (thermal)

Cost Information

This analysis assumes that the costs for all components outside of major hardware, software, and maintenance costs are equivalent among detection technologies (i.e. wiring and man-hours for installation). The initial step in obtaining these costs was reaching out to manufacturers and ODOT officials through an informal survey. The second step was through direct email to the specific manufacturers and practitioners. A final attempt to capture pertinent cost information was made through using national institution forums such as the Institute of Transportation Engineers (ITE). Cost information and detection configurations came in the form of completed surveys, bid sheets, traffic engineer cost estimates, and personal emails. According to the National Safety Council, the costs of motor-vehicle injuries for 2014 are $1,512,000 for a crash resulting in a fatality and $88,500 for a crash resulting in an incapacitating injury (10). These values were utilized to determine the additional benefits required to justify choosing a more expensive alternative.

RESULTS AND DISCUSSION

Vehicle Detection – 1 Intersection | 10 years

This scenario compares the life cycle costs of each type of vehicle detection for one intersection over a ten-year analysis period. This analysis captures the per intersection costs including total initial cost, total present annual cost, and total present replacement cost for each type of vehicle detection. This analysis is instrumental as typical vehicle detection technologies are replaced with newer emerging technologies after a 10-year life span.

Shown in Figure 1 and Table 1, inductive loop detection has the lowest life cycle cost for a ten-year analysis period at $19,500 for a single intersection. The alternative with the highest life cycle cost is Wavetronix Radar at $85,469 which consists of $46,520 in initial costs and $38,949 in annual costs for maintenance and troubleshooting.

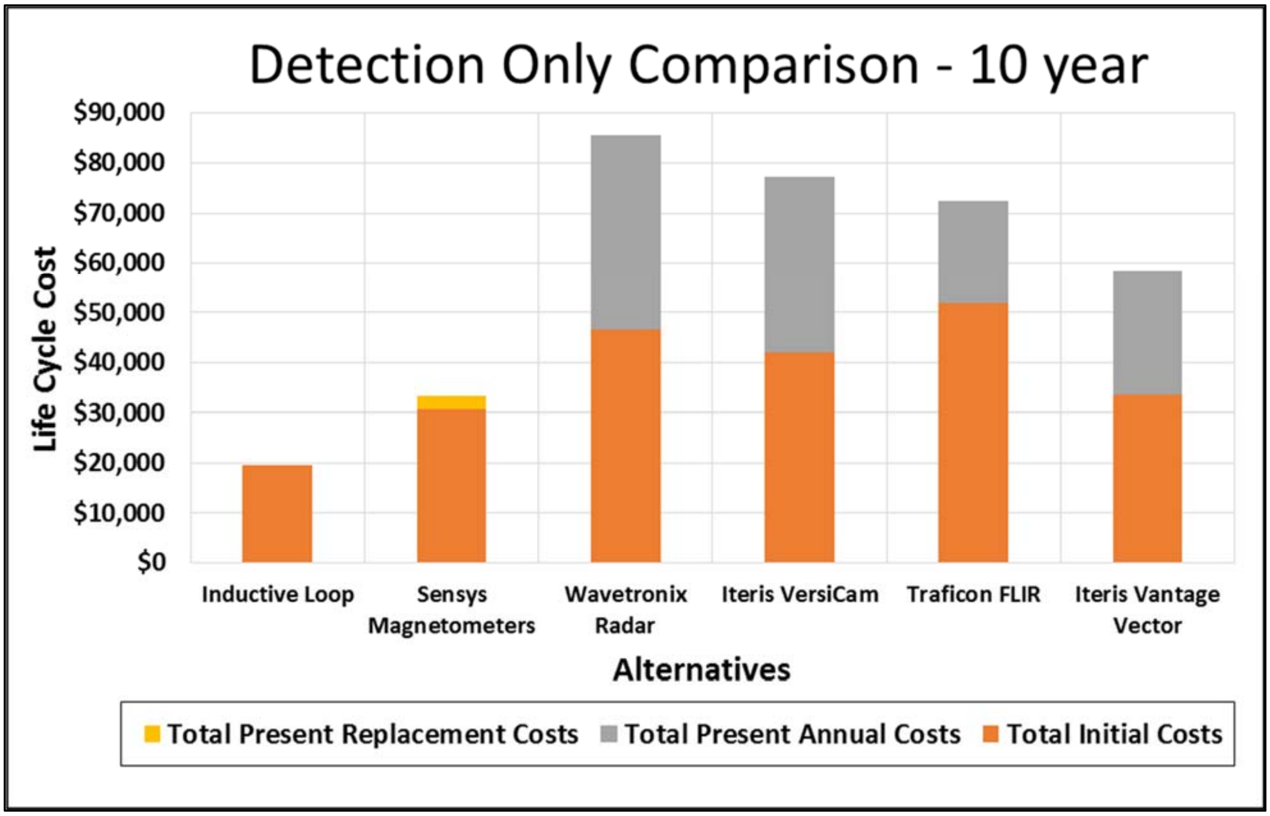

Figure 1: Detection only comparisons for 1 intersection over 10 years

Table 1: Detection only comparison results for 1 intersection over 10 years

Alternative	Total Initial Costs	Total Present Annual Costs	Total Present Replacement Costs	Life Cycle Cost	Percent Increase in Cost Compared to Lowest
Inductive Loop	$19,500	$0	$0	**$19,500**	*0.0%*
Sensys Magnetometer	$30,700	$0	$2,751	**$33,451**	*71.5%*
Wavetronix Radar	$46,520	$38,949	$0	**$85,469**	*338.3%*
Iteris VersiCam	$42,000	$35,255	$0	**$77,255**	*296.2%*
Traficon FLIR	$51,984	$20,327	$0	**$72,311**	*270.8%*
Iteris Vantage Vector	$33,520	$24,880	$0	**$58,400**	*199.5%*

The results reveal that inductive loops not only have the overall lowest life cycle cost and also the lowest initial cost. When considering which detection to use for a long term deployment, other factors must be considered including annual maintenance costs and the accompanying traffic control. The required operational improvements the higher costing alternatives must overcome to be considered preferred are shown in Table 2.

Table 2: Detection only user costs results for 1 intersection over 10 years

Alternative	Required User Time Savings (hour / day)		Required Change in Crashes	
	Autos	**Trucks**	**Fatalities**	**Incapacitating**
Inductive Loop	0.00	0.00	0.00	0.00
Sensys Magnetometer	0.23	0.05	0.01	0.18
Wavetronix Radar	0.97	0.20	0.04	0.75
Iteris VersiCam	0.85	0.18	0.04	0.75
Traficon FLIR	0.78	0.16	0.03	0.60
Iteris Vantage Vector	0.57	0.12	0.03	0.44

Radar is the most expensive alternative in this analysis set, however it has the ability to project vehicle arrivals to the stopbar. This ability can provide an increase in efficiency, as better knowledge of vehicle arrivals can assist in the reduction of unintended max-outs, as well as improve the safety of operations, as the exact position of each vehicle within the 'dilemma zone' is known. Video was the second most expensive alternative, but the ability of video to dynamically change the size of the active detection zone can translate into efficiency gains in situations with a large percentage of heavy vehicles within the mix.

The table above shows that required user time savings and reduction in crashes each alternative must result in to be considered the more preferred alternative. If the deploying agency wishes to utilize radar detection for dilemma zone protection or video for other operational benefits, they would need to see an equivalent decrease of 0.04 crashes resulting in fatalities over the analysis period, or 0.75 decrease in crashes resulting in incapacitating injuries. This is one example of other considerations that must be considered when selecting vehicle detection to run a signal control technology.

Signal Control – 10 Intersections | 10 Years

This scenario compares the life cycle costs for each type of signal control technology for ten intersections over a ten-year analysis period. This analysis is included in this study to provide an examination of the isolated life cycle costs for each signal control technology. Additionally, in the event that an ASCT is installed using existing detection, this comparison scenario provides a structured approach to analyzing signal control technologies without the additional costs of vehicle detection.

Shown in Figure 2, coordinated signal timing has the lowest life cycle cost for a ten year analysis period. For ten intersections the initial cost for coordinated signal timing is $37,600 for the individual signal timing plans, and the annual cost is $102,362 for retiming every three years. The highest life cycle cost is Transcend at $350,000. The costs that compose each life cycle cost are shown in Table 3.

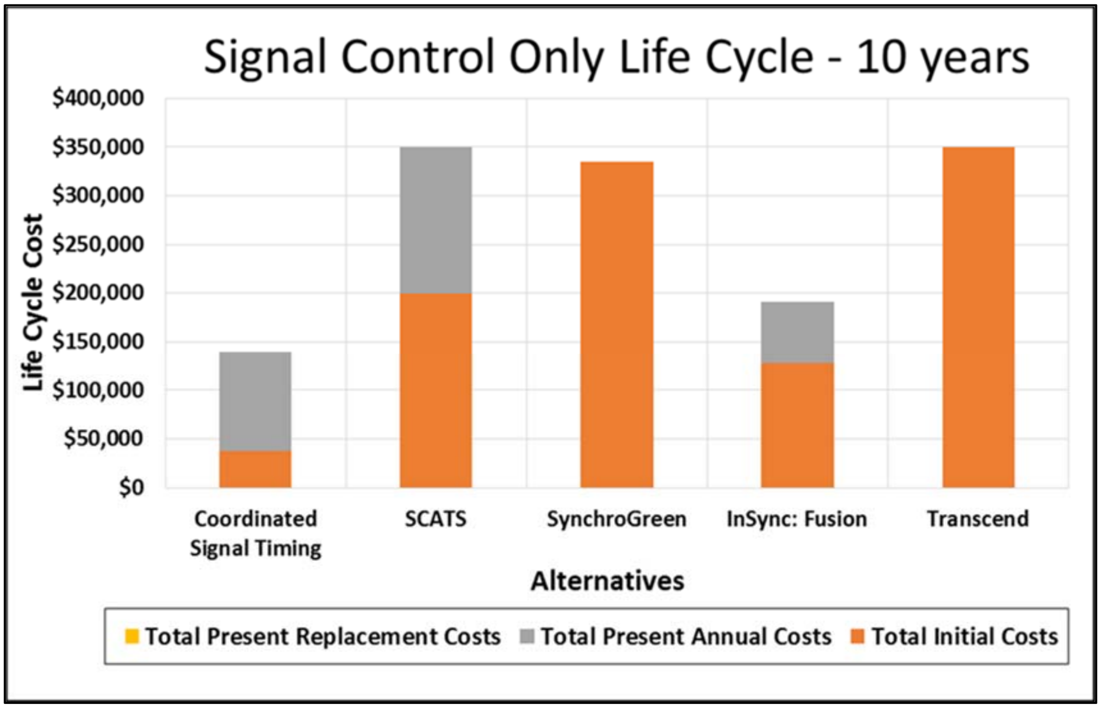

Figure 2: Signal Control Comparison for 10 year analysis

Table 3: Signal control results for 10 year analysis

Alternative	Total Initial Costs	Total Present Annual Costs	Total Present Replacement Costs	Life Cycle Cost	Percent Increase in Cost Compared to Lowest
Coordinated Signal Timing	$37,600	$102,362	$0	**$139,962**	0.0%
SCATS	$200,000	$149,279	$0	**$349,279**	149.6%
SynchroGreen	$335,000	$0	$0	**$335,000**	139.3%
InSync: Fusion	$127,500	$63,977	$0	**$191,477**	36.8%
Transcend	$350,000	$0	$0	**$350,000**	150.1%

This analysis shows over a ten-year period InSync: Fusion adaptive control has slightly higher life cycle cost than the cost of running a roadway network in standard coordination (36.8%). However, SCATS, SynchroGreen, and Transcend will all have a life cycle cost at least double of InSync: Fusion. Shown in Table 4, consideration should be given to the additional advantage gained from opting to use any of these more expensive alternatives over utilizing basic coordinated signal timing plans that are retimed every three years.

Table 4: Signal control results for 10 year analysis

Alternative	Required User Time Savings (hr / day)		Required Change in Crashes	
	Autos	Trucks	Fatalities	Incapacitating
Coordinated Signal Timing	0.00	0.00	0.00	0.00
SCATS	3.09	0.65	0.14	2.37
SynchroGreen	2.88	0.60	0.13	2.20
InSync: Fusion	0.76	0.16	0.03	0.58
Transcend	3.10	0.65	0.14	2.37

Vendor Recommended Installation

Each of the ASCT vendors provide a recommended vehicle detection layout which should be installed by agencies to optimize the adaptive system. This scenario provides a comparison of the vendor recommended vehicle detection installation. In some cases, such as SynchroGreen and InSync: Fusion, the vendors only specify which detection zones are required, but leave the type of detection up to the agency deploying the system. In such cases, this research assumes that inductive loops are the preferred method of detection as previous work has shown that loops tend to be more accurate and less expensive (11).

Table 5 shows the vendor recommended detection configurations for each type of signal control. Figure 3 shows the results of the vendor recommended installation analysis. Figure 3 and Table 6 show InSync: Fusion has the lowest life cycle cost of $332,477 consisting of $268,500 in initial costs and $63,977 in annual costs. Coordinated signal timing has the second highest life cycle cost by 0.7% of $334,962 consisting of $232,600 in initial costs and $102,362 in annual costs.

Table 5: Vendor Recommended Detection Configuration

Signal Control Technology	Vendor Recommend Detection Configuration			
	Major Stopbar	**Major Advanced**	**Minor Stopbar**	**Minor Advanced**
Coordinated Signal Timing	Inductive Loop	Inductive Loop	Inductive Loop	Inductive Loop
SCATS	Inductive Loop	None	Inductive Loop	None
SynchroGreen	Agency Choice*	Agency Choice*	Agency Choice*	Agency Choice*
InSync: Fusion	Agency Choice*	None	Agency Choice*	None
Transcend	Inductive Loop	Agency Choice*	Inductive Loop	Agency Choice*

Agency Choice* = inductive loops for vendor recommended comparison

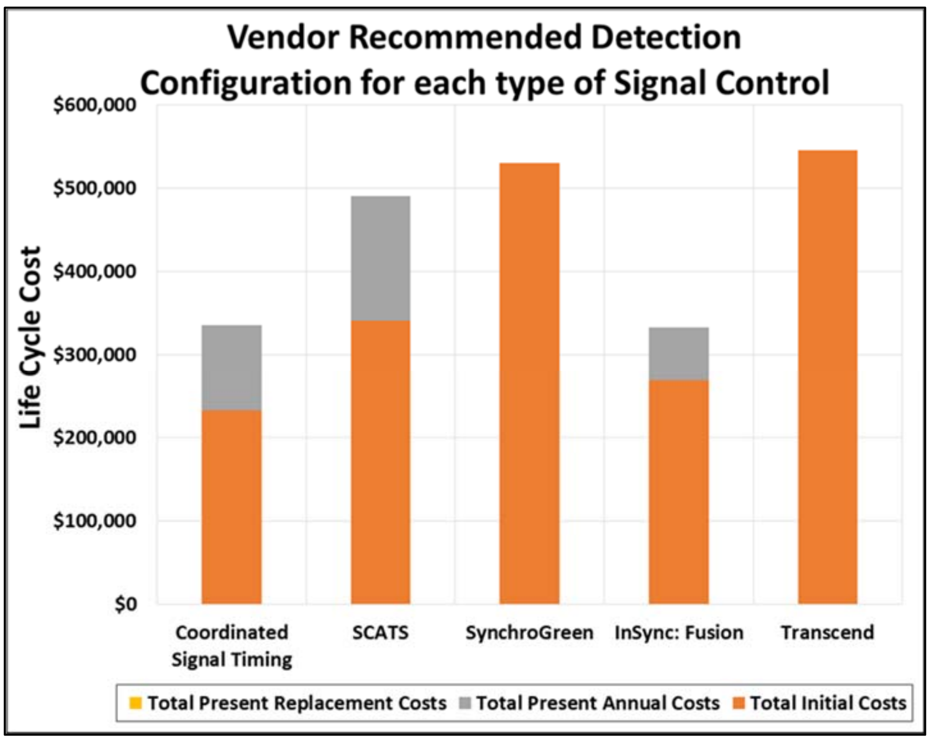

Figure 3: Vendor Recommended Detection Configuration

Table 6: Vendor recommended detection configuration numeric results

Alternative	Total Initial Costs	Total Present Annual Costs	Total Present Replacement Costs	Life Cycle Cost	Percent Increase in Cost Compared to Lowest
Coordinated Signal Timing	$232,600	$102,362	$0	**$334,962**	0.7%
SCATS	$341,000	$149,279	$0	**$490,279**	47.5%
SynchroGreen	$530,000	$0	$0	**$530,000**	59.4%
InSync: Fusion	$295,500	$63,977	$0	**$332,477**	0.0%
Transcend	$545,000	$0	$0	**$545,000**	63.9%

Table 7 summarizes the required user time savings in hours per day and required reduction in crashes by fatalities and incapacitating injuries during the ten-year analysis period that the higher cost alternatives must produce in order to be considered the more preferred alternative in comparison to the life cycle cost of InSync: Fusion.

Table 7: Vendor recommended detection user cost results

Alternative	Required User Time Savings (hour / day)		Required Reduction in Crashes (per 10 years)	
	Autos	Trucks	Fatalities	Incapacitating
Coordinated Signal Timing	0.04	0.01	0.00	0.03
SCATS	2.33	0.49	0.10	1.78
SynchroGreen	2.92	0.61	0.13	2.23
InSync: Fusion	0.00	0.00	0.00	0.00
Transcend	3.14	0.66	0.14	2.40

Inductive Loop Sensitivity Analysis Results

This comparison scenario provides the additional cost associated with a shortened life span of inductive loops detectors. Inductive loops consistently produced the lowest life cycle cost throughout this research. This is a result of inductive loops not requiring any annual maintenance or troubleshooting, which further decreases there cost as there is no addition traffic control cost associated with maintenance. However, as inductive loops are an invasive detection, they are sometimes subject to needing replacement as a result of construction, pavement failure, freeze thaw cycles, or vermin. Figure 4 shows the loop life span sensitivity analysis for ten intersections over ten years. The sensitivity analysis reveals that as the lifespan of a loop detector is shortened, the life cycle cost increases exponentially. Decreasing the life span from ten years to six years results in an increase in life cycle cost of 50%. However, decreasing the life span from five years to one year results in an increase in life cycle cost of 596%. Therefore, careful consideration should be made for networks that desire to utilize inductive loops as their source of vehicle detection, but may encounter shorter loop detector lifespans as a result of repeated construction, extreme freeze thaws, or other factors mentioned previously.

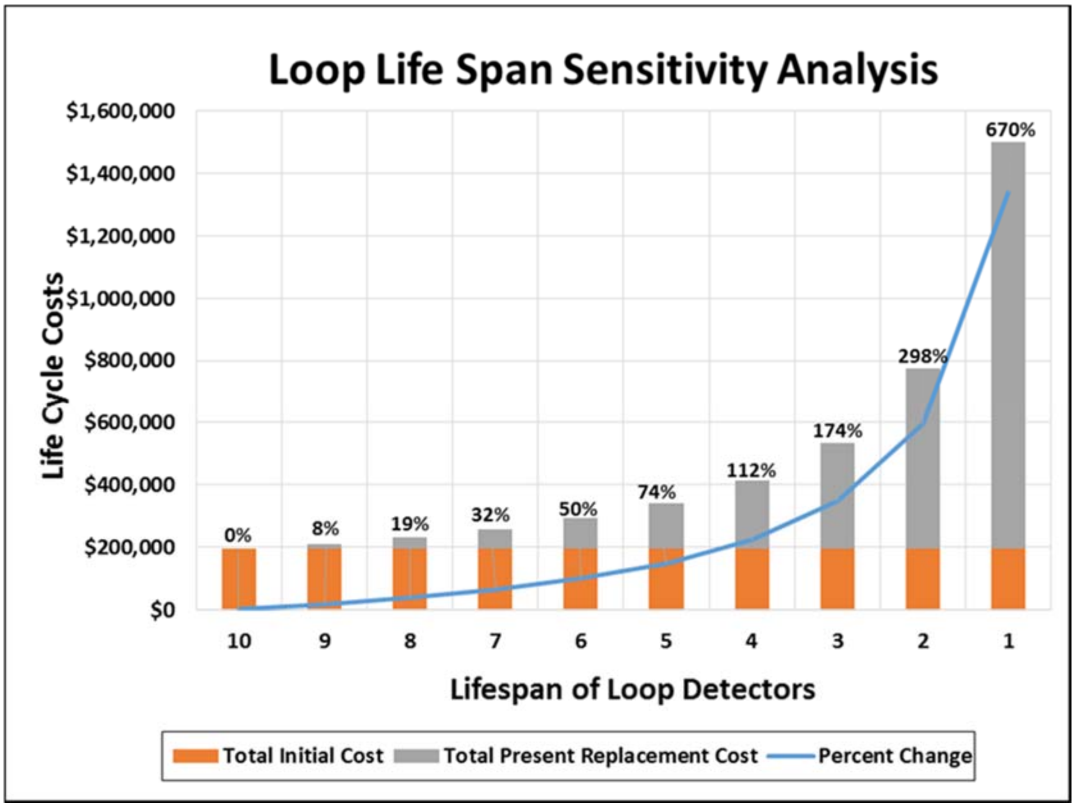

Figure 4: Loop life span sensitivity analysis

CONCLUSION

This paper presented a summary of previous work in life cycle cost analyses in transportation, adaptive signal control cost studies, and operations and maintenance studies. Additionally, the background of adaptive systems, vehicle detection, operations and maintenance, and life cycle cost analysis was discussed. The life cycle cost analysis tool was introduced and the operations of the tool were presented. Finally, the results and associated discussion were presented.

No previous work has combined vehicle detection, adaptive systems, and operations and maintenance for a life cycle cost analysis with monetary elements as the reported results. As more adaptive systems and newer vehicle detection technologies emerge, it is paramount that agencies are provided tools which inform them of long term life cycle costs. This research provides a LCCAT which considers vehicle detection, adaptive systems, and operations and maintenance which gives life cycle costs in dollar amounts broken into initial, annual, and replacement components. Although the preferred detection configurations had similar initial costs for all signal control technologies, the difference in annual maintenance cost was the prevailing factor which set each configuration apart. This also holds true for vehicle detection technologies, as inductive loops do not require an annual maintenance and were found to be the cheapest alternative throughout. Therefore, annual maintenance and operational costs are key factors in the life cycle cost of signal control systems. The results of this research can be conveyed to transportation agencies and used to provide recommendations toward installing future adaptive signal control and vehicle detection technologies

Future work should continue to build on the LCCAT by gathering and including more signal control and vehicle detection costs within the tool. Additionally, the LCCAT allows for a comparison among similar technologies, such as video detection, but from different vendors.

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