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Concept of Operation for: A New Tool for Signalized Intersection Performance Assessment

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System-wide Assessment of Intersections Level of Service

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Title	System-wide Assessment of Intersections Level of Service Using Big Data to Identify and Prioritize Deficient Locations.
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Abstract	<p>There are a large number of traffic signals in each city to manage intersections. However, in Tennessee, signal retiming periods for most of the intersections are more than two years, which can lead to performance degradation, delay, and deficiency. Besides, different agencies utilize different signal equipment which is typically challenging to aggregate and connect them. Also, smaller agencies usually rely on contractors to service their intersections. Small agencies cannot afford expensive equipment for traffic signal management. In this concept of operation, we propose an ITS solution to these problems. The proposed method develops the use of Big Data to identify and prioritize deficient locations in term of Level of Service (LOS). This method uses crowdsourced data (e.g., Waze data) and eliminates the need for installing new equipment and devices in each intersection for data collection. Using Waze data can address travel time in different segments and intersections every minute. Hence, we can propose a method to calculate real-time delay and LOS of intersections. This calculation leads to identify the deficient intersections. Also, it is capable of helping the Tennessee Department of Transportation (TDOT) rank the corridor and make better decisions to allocate their funding. Finally, by calculating travel time, delay and LOS of different intersections, segments, and corridors in different periods, we can develop a Deep Learning methodology to provide a real-time dynamic signal timing for various intersections. Travel time delay analysis, corridor performance management, intersection evaluation, and a method for dynamic signal timing based on Big Data are among deliverables that our approach facilitates.</p>
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ABSTRACT

There are a large number of traffic signals in each city to manage intersections. However, in Tennessee, signal retiming periods for most of the intersections are more than two years, which can lead to performance degradation, delay, and deficiency. Besides, different agencies utilize different signal equipment which is typically challenging to aggregate and connect them. Also, smaller agencies usually rely on contractors to service their intersections. Small agencies cannot afford expensive equipment for traffic signal management. In this concept of operation, we propose an ITS solution to these problems. The proposed method develops the use of Big Data to identify and prioritize deficient locations in term of Level of Service (LOS). This method uses crowdsourced data (e.g., Waze data) and eliminates the need for installing new equipment and devices in each intersection for data collection. Using Waze data can address travel time in different segments and intersections every minute. Hence, we can propose a method to calculate real-time delay and LOS of intersections. This calculation leads to identify the deficient intersections. Also, it is capable of helping the Tennessee Department of Transportation (TDOT) rank the corridor and make better decisions to allocate their funding. Finally, by calculating travel time, delay and LOS of different intersections, segments, and corridors in different periods, we can develop a Deep Learning methodology to provide a real-time dynamic signal timing for various intersections. Travel time delay analysis, corridor performance management, intersection evaluation, and a method for dynamic signal timing based on Big Data are among deliverables that our approach facilitates.

TABLE OF CONTENTS

Description of problem	1
Objectives.....	2
Requirements.....	2
Stakeholders	2
Problem Scopes.....	3
Description of solution.....	3
Description of data.....	4
Waze Travel Time Data	4
Calculating LOS.....	4
Waze travel time collection	5
Average Travel Time Delay Computation	6
Travel Time Delay Analysis and Deficiency Identification	6
Prioritize Intersections.....	7
Prioritize Corridors.....	7
Before-After Analysis	7
High-Level Architecture of the Proposed System.....	8
Expected Benefits and Implementations.....	8
Expected Benefits	8
Implementation	9
Cost breakdown and Timeline	9
Conclusions	10
References	11

LIST OF TABLES

Table 1: Level of Service Criteria for Signalized Intersections (4)..... 5

Table 2: Anticipated benefits of solutions. 9

Table 3: Anticipated cost breakdown and timeline of solution implementation. 10

LIST OF FIGURES

Figure 1. Signal Ownership in Tennessee. 1

Figure 2. Signal retiming period in Tennessee..... 1

Figure 3. Framework of stakeholders’ relations. 3

Figure 4. Waze data retrieval..... 4

Figure 5. Data collection method for a four-way signalized intersection. 6

Figure 6. High level architecture of the proposed system. 8

LIST OF ACRONYMS

TDOT	Tennessee Department of Transportation
LOS	Level of Service
ITS	Intelligent Transportation system
CCP	Connected Citizens Program
HCM	Highway Capacity Manual
TTSUG	Tennessee Traffic Signal User Group
GIS	Geographic Information System
PDF	Probability Density Function

DESCRIPTION OF PROBLEM

Metropolitan areas and smaller cities host thousands of traffic signals. Traffic signals play an important role in transportation mobility systems and traffic management. Implementing different traffic signals system strategies and projects typically can lead to reducing traffic congestion, preventing incidents, and improving Level of Service (LOS) in a signalized intersection (1-3). There are more than 6,000 operating traffic signals in Tennessee; however, Tennessee Department of Transportation (TDOT) does not typically provide a centralized system to operate

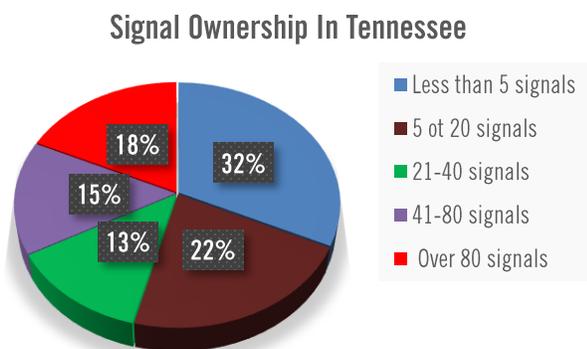


Figure 1. Signal Ownership in Tennessee.

and maintain traffic signals. Ownership, along with responsibility for operation and maintenance, reverts to the local governing agency. A survey conducted by TDOT Tennessee Traffic Signal User Group (TTSUG) shows the signal ownership in Tennessee (Figure 1). Local agencies demonstrate a different level of abilities in maintaining traffic signals. Lack of necessary technical expertise in smaller agencies is one of the reasons for these differences in traffic signal maintenance; therefore, smaller agencies typically rely on contractors to service their intersections. Consultants usually modify the timing plans due to unusual repetitive events (e.g., crashes and complains) or citizen complaints.

Another survey conducted by Tennessee Traffic Signal User Group (TTSUG) demonstrates the signal retiming periods of agencies that own a different number of signals (Figure 2). It is evident that most agencies perform retiming either over two years or never. The concern is that these agencies lack an effective way to assess the benefits of signal retiming. These facts show that most signalized intersections in the TN State are not monitored or supervised on a regular, systematic, standard, successive, and instantaneous basis. This issue can indeed cause performance degradation, delay, and deficiency.

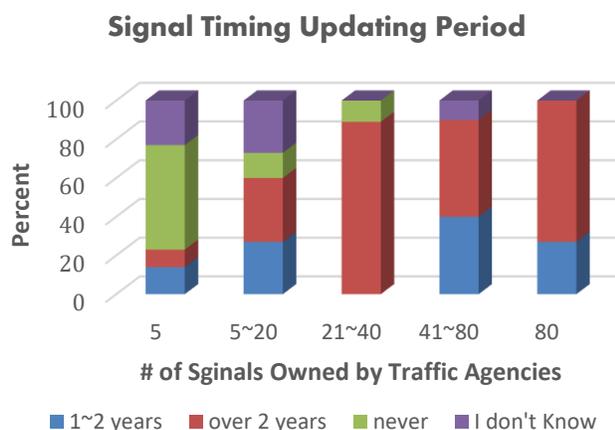


Figure 2. Signal retiming period in Tennessee.

This problem might have been nondescript in the past due to technology and costs. However, with improvement of emerging technologies, accessibility to crowd-sourced data (e.g., Waze,

HERE, etc.), and Big Data approaches, the state can eliminate this problem by design a system that helps agencies to identify deficient signalized intersections and automatically generate performance reports periodically for both monitoring and evaluation of implementation effect purposes.

Objectives

As discussed, this report is trying to address an existing problem in Tennessee. For this purpose, an Intelligent Transportation system (ITS) solution will be proposed. Based on experiences of previous TDOT research projects which this team (authors of this report) had been engaged in, TDOT embraces ITS solutions and proposals for this problem. This report aims to “propose an ITS solutions to employ Big data collected from crowdsources and Deep Learning techniques to identify the LOS of signalized intersections, rank deficient traffic signals and improve signal timing plans in a network level.” This objective can improve performance, reduce delay, and improve safety and can also be timely and economically efficient due to fast deployment and no needs of additional hardware.

Requirements

The proposed solution aims to improve efficiency, reduce delay and improve operation. For this purpose, this project needs to access crowdsourced data such as Waze inventory data, intersections’ GIS data, and signal timing plans. This solution requirements are presented as follow:

- assessing the LOS and travel time based on Big data collected from Waze.
- Reducing the analysis cost by using crowdsourced data instead of implementing new equipment’s.
- Identifying deficient intersections.
- Improving LOS of deficient intersections.
- Presenting a real-time dynamic system using Deep Learning.

Stakeholders

Figure 3 presents a framework of interaction between stakeholders. In this framework, TDOT is taking supervision role and provides some policies, funds, and data for this project. Partnership with universities and consultants will result in designing and maintenance of this system. Also, road users are the beneficiary of this system. They also can play a role as a probe vehicle and help the system data collection.

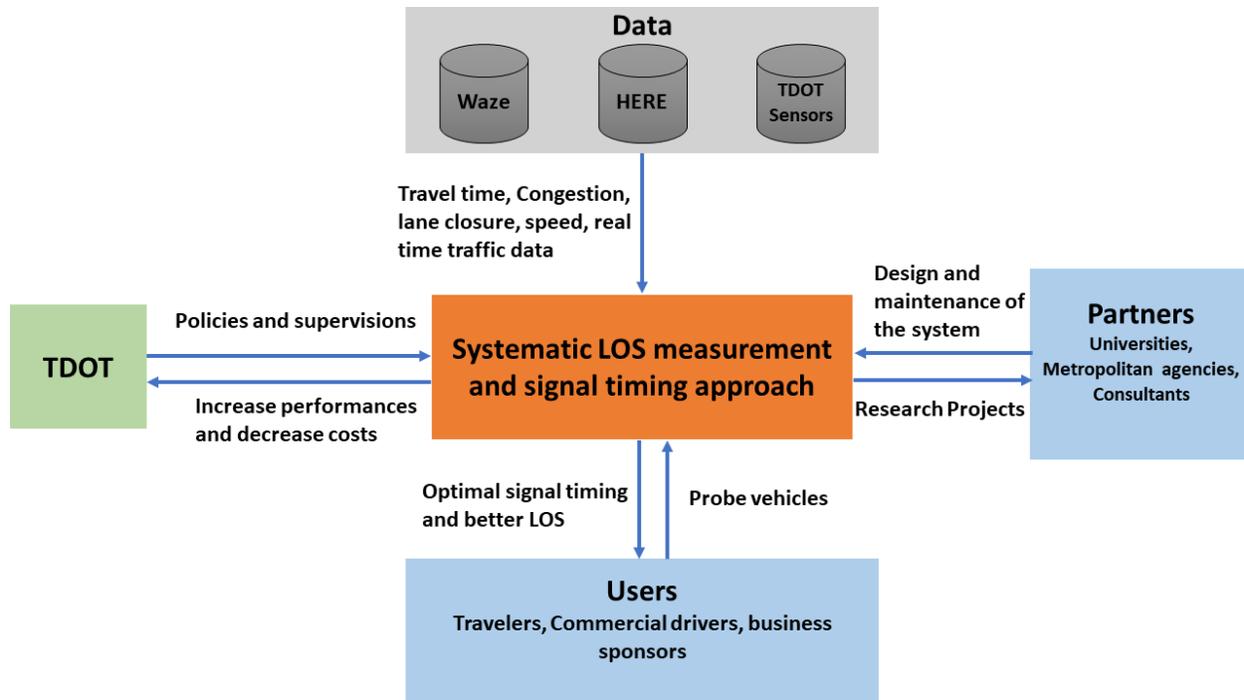


Figure 3. Framework of stakeholders' relations.

Problem Scopes

The proposed solution is essential and challenging in many ways. The study is scoped in the following order to make it more manageable and prosperous.

- The main focus of this solution will be on signalized intersections in Tennessee.
- The proposed solution is mainly a research project. This study can develop the algorithms, assess strategies, and design the infrastructures and servers to implement the system.
- This solution might have some limitations due to the availability of data on some sites.

To reach the objectives in this scope, first, the data for different sites should be collected. Fortunately, TDOT has an agreement successfully with Waze through Connected Citizens Program (CCP) to share data. In terms of travel time and incident reports, a critical crowdsourced data can be collected for this solution.

DESCRIPTION OF SOLUTION

The study aims to use crowdsourced data to analyze and evaluate the performance of signalized intersections on a system-wide basis to support TDOT to diagnosis the problems and prioritize deficient locations for improvements. The approach proposed in this study requires intersection travel time data.

Description of data

Bluetooth and Wi-Fi sniffer detectors can be used to track the vehicles traveling intersections and provide traffic speed data along a stretch of roadway. However, it is almost impractical to have those devices installed at every intersection. The initial cost and maintenance fee is expected to be high.

In recent years, with the ubiquitous use of mobile phones and GPS devices, probe vehicle data has become one of the primary data sources in transportation. Probe vehicle data are mostly provided by private commercial vendors, such as INRIX, TomTom, and HERE. The data provided by those agencies are traffic speed and travel time along a stretch of road way during a fixed period that is similar to data provided by Bluetooth, but at a lower cost and with a higher coverage.

In this proposal, crowdsourced-based probe vehicle data is adopted. TDOT has established partnerships with Waze through Connected Citizens Program (CCP) to share data. Based on the agreement, Waze provides TDOT with travel time and traffic speed data as well as traffic jam level on designated links, which is the main dataset used in this research. The solution provided in this proposal can be applied with any probe vehicle data set.

Waze Travel Time Data

Waze provides traffic view tool which allows traffic agencies to manage a list of road segments that named Watch-list. Traffic agencies can add any routes of their interests to the Watch-list, travel time and traffic speed information for road segment is available and updated on a 1-min basis in real-time. The Waze data retrieving procedure is provided in Figure 4. First, add routes to the watch-list, then once the Waze traffic view toll update the travel time for the road segment, the data can be retrieved and archived in real-time in data management center.

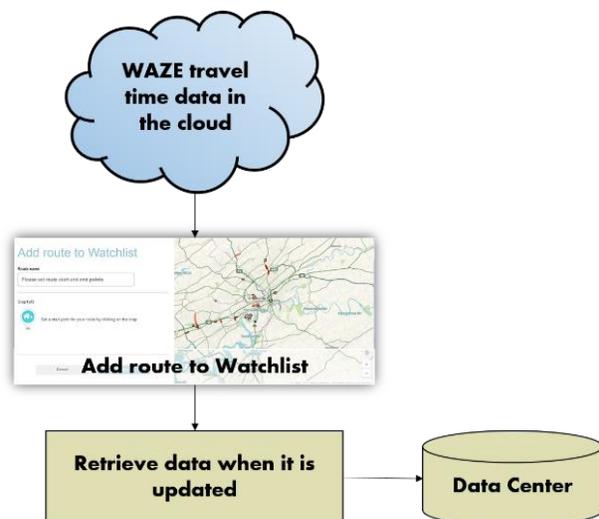


Figure 4. Waze data retrieval.

Calculating LOS

The first part of the proposed solution addresses using real-time speed data to evaluate the performance of a single signalized intersection on a continuing basis. An approach based on crowdsourced data is provided and compared to the conventional methods.

Based on Highway Capacity Manual (HCM) the LOS of a signalized intersection can be defined as Table 1 (4).

Table 1: Level of Service Criteria for Signalized Intersections (4).

LOS	Average Control Delay (Second per vehicle)	Description
A	≤10	Free Flow
B	>10-20	Stable Flow (slight delays)
C	>20-35	Stable flow (acceptable delays)
D	>35-55	Approaching unstable flow (tolerable delay, occasionally wait through more than one signal cycle before proceeding)
E	>55-80	Unstable flow (intolerable delay)
F	>80	Forced flow (congested and queues fail to clear) or v/c ratio over 1

In this section, first, the conventional methods of calculating LOS will be discussed; then, the proposed method in this study will be provided. In the conventional method, the average delay for a signalized intersection can be formulated with signal cycle time, the ratio of effective green to signal cycle time, the ratio of flow over capacity, flow, capacity, and some calibration factors. To calculate these measures, agencies, and consultant typically (i) count the number of vehicles in an intersection twice a year or (ii) equip the intersection with some facilities to continuously count the vehicle number. The former is not accurate and provide different errors, and the latter is usually costly. Also, these traffic counting technologies might not be consistent between different cities and intersections.

This solution utilizes Waze data to calculate average travel time and delay and identify the LOS of each intersection. The proposed method has various advantages (reducing cost, eliminating errors, real-time capabilities, etc.) over conventional method.

Waze travel time collection

As mentioned before, Waze allows users to create routes and provide travel time and traffic speed information for the designated road segment. To ensure the data reliability, a minimum road segment of 16 feet is recommended. This feature supports the applicability of our proposed methodology.

As shown in Figure 5 a typical four-way signalized intersections with four paths is depicted. In this illustration, each path may have three traveling directions; separately right turn, go straight and left turn. Travel time data can be collected for each direction by creating corresponding traveling routes. A road segment for each direction is created, as shown in figure 5, for northbound traveling directions, all the road segments start at a upstream point P_u , which locates at the nearside of the intersection, and extend to a downstream point P_d (P_{ld}, P_{rd} represent the

corresponding left turn and right turn downstream point), which locates at the far-side of the intersection. The road segment then is generated, and the travel time along the road segment can be retrieved.

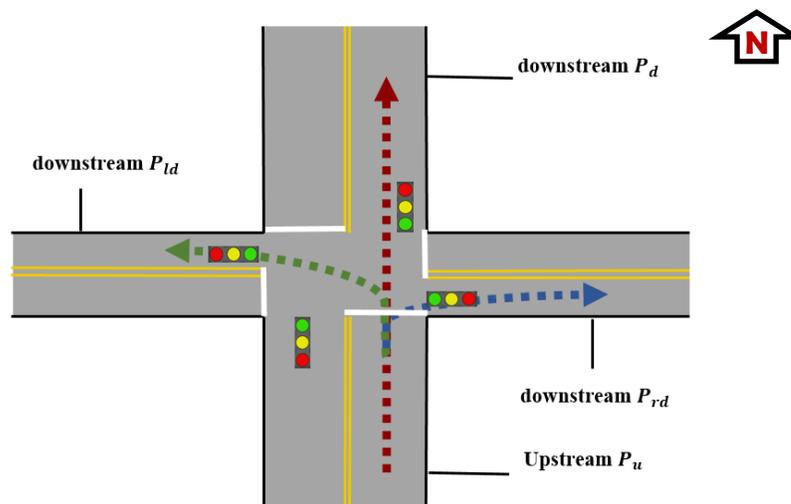


Figure 5. Data collection method for a four-way signalized intersection.

One of the critical parts of this approach is to determine the location of P_d and P_u . If P_d is located close to the intersection, the queue might propagate further upstream, leads to an underestimation of the delay of this direction. Similarly, if P_u is located far from the intersection, the calculated delay might involve the delay caused by other factors, such as delay of next intersection or vehicles entering the road segments from branches. The location shall be selected with cautious.

Average Travel Time Delay Computation

Average travel time delay is defined as extra time spent by drivers against their expectation. The average time \bar{T} spent by drivers is given. The expected travel time can either be defined as total length/speed limit T_e or can be defined as free flow travel time T_f , which can be calculated using probability density function (PDF). Travel time PDF is easy to obtain since \bar{T} is given every 1-min. Therefore, the Average Travel Time Delay \bar{D} can be calculated as: $\bar{D} = \bar{T} - T_e$ or $\bar{D} = \bar{T} - T_f$. Which one works the best is to be determine by the analysis results. Notice that like \bar{T} , \bar{D} also varies every 1-min, this feature supports many future analyses.

Travel Time Delay Analysis and Deficiency Identification

Using the proposed process in methodology section, the average vehicle travel time delay and LOS of each intersection can be obtained every minute for each traveling direction. The delay shall be aggregated to an interval to provide more general information; it is recommended that

the traffic delay for each path automatically aggregated into multiple intervals. An example would categorize the traffic delay during peak hour into the same category. This helps the traffic control agencies to evaluate the performance of the intersection at a different time of the day and different weekdays. The pattern of the traffic delay requires comprehensive analysis to provide the traffic agencies enough knowledge and understanding of the performance of the signalized intersections.

Prioritize Intersections

To effectively identify the deficient signalized intersections, different evaluation criteria can be proposed to rank intersections. The traffic delay can be aggregated to peak hour delay, average daily delay by critical direction or all directions. The effectiveness of the signalized intersection will thus be analyzed from different perspectives. In addition, TDOT owns AADT data at some locations, combining the traffic flow data with the travel time delay helps TDOT identify the intersections with less traffic flow but higher travel time delay.

Prioritize Corridors

Corridor management is one of the main tasks of TDOT TSM&O division. Average travel time delay can be aggregated along a corridor directly computed for a corridor to assess the performance for the critical direction. This helps TDOT rank the corridor and make better decisions to allocate their funding.

Before-After Analysis

To evaluate the safety and efficiency benefits of TDOT's efforts towards improving signalized intersection performance, quantitative evaluations can be conducted with the availability of travel time delay data. The improvements can be measured from multiple aspects, such as reduction in average delay, travel time reliability improvements. Also, the analysis can be conducted with a different time range to assess both the short-term and long-term benefits of the improvements.

Finally, with the analysis of various intersections, a Deep Learning method can be implemented to assess dynamic and real-time signal timing plan to improve LOS. Based on the data which we discussed, we can calculate travel time, delay and LOS of each intersection, segment and corridor during different periods and in real-time status. We can aggregate the travel time of different segments in a corridor and analyses the system-wide traffic. Based on this valuable methodology, we can utilize a Deep Learning method to optimize the signal timing and reduce overall delay. The real-time method helps TDOT to improve the system. This can also benefit TDOT during evacuation or special days traffic.

High-Level Architecture of the Proposed System

Figure 6 presents a high-level architecture of the proposed system. The first part of the system mainly focuses on travel time delay calculation and performance reports generation. The second part of the system includes using the results from the first part to conduct analysis and supports TDOT to better allocate their funding.

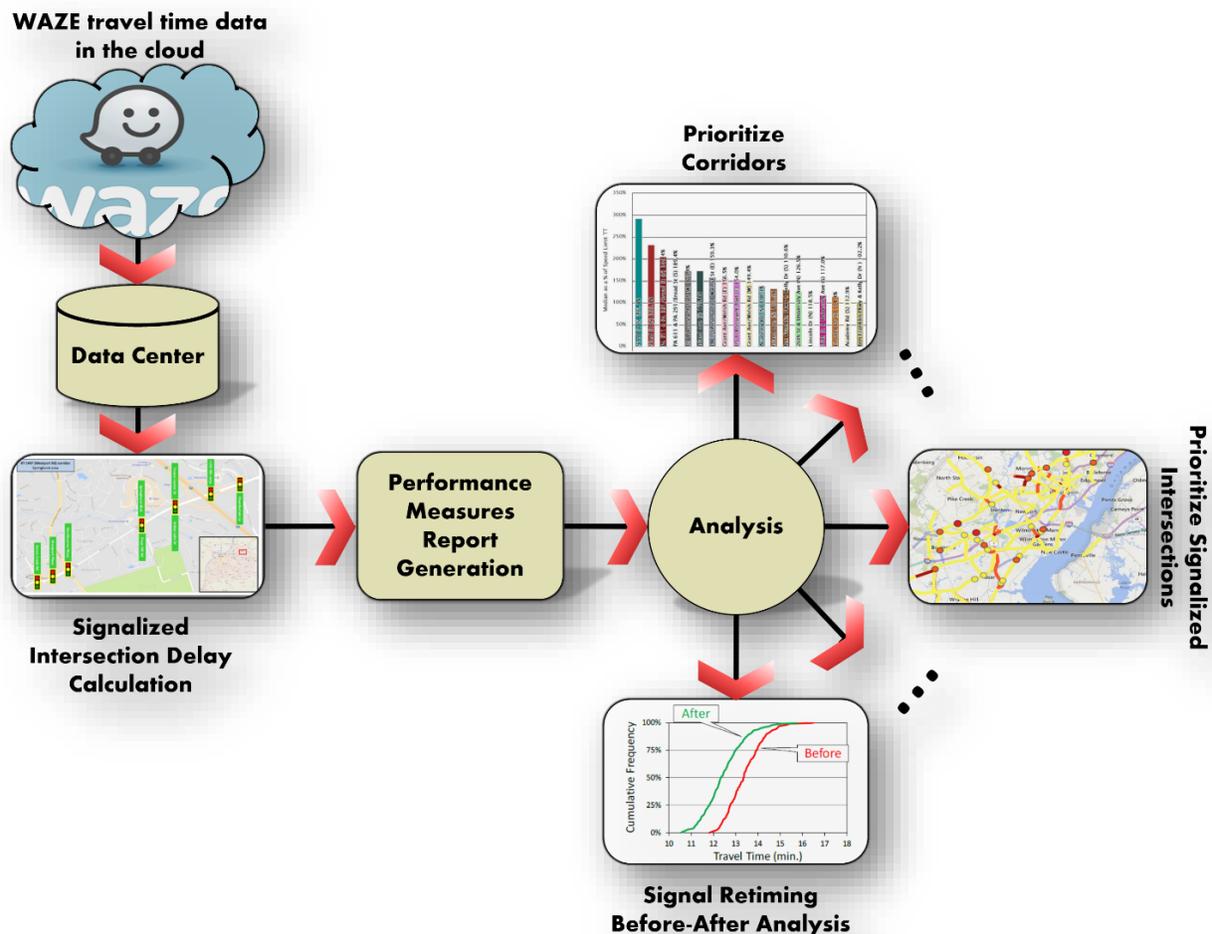


Figure 6. High level architecture of the proposed system.

EXPECTED BENEFITS AND IMPLEMENTATIONS

Expected Benefits

The deliverables of the proposed solutions will provide factual statistics backed by sound analysis to assist traffic signal maintenance and performance evaluation. The travel time delay calculation results can be compared to conventional method and identify where the discrepancies are, further analysis of the discrepancies and help to improve both methods. The deficient analysis is

expected to have numerous benefits. It provides a low-cost solution to proactive signalized intersection management and performance evaluation. Beyond that, the solution provides a comprehensive view of signalized intersections performance on a system-wide basis and helps TDOT conduct retiming project and make important investment decisions to serve the motoring public best. The ad-hoc analysis assists TDOT in demonstrating the effectiveness of optimization efforts. Furthermore, the system provides an ongoing performance measurement analysis, this active performance management is easy to implement and can be operated by technicians that without high-level training experiences, the constant monitoring of the traffic signal is able to provide insight into the signalized intersection and promote the understanding of the dynamics of the signalized intersections of traffic practitioners. The anticipated impacts and benefits are summarized in table 2.

Table 2: Anticipated benefits of solutions.

Operational benefits	Improve the efficiency of signalized intersection management
Safety benefits	Improve signalized intersection safety by providing traffic practitioners better understanding of the performance of the intersection and make better decisions about signal retiming.
Mobility benefits	Reduce travel time delay at intersections and increase travel time reliability.
Economic benefits	Provide a low-cost performance management system, no additional hardware/infrastructure investments are needed
Environmental benefits	Reduce emissions by reducing traffic delay

Implementation

The system produces consistent results and is easy to be implemented. The Automated traffic signal performance measure system includes following features:

- The system is easy to set up and data is easy to retrieve.
- The system can store data for future retrieval.
- The system monitors the system-wide signalized intersections and produces consistent output.
- The system produces simplified results that can be easily presented to and understood by technicians and public.
- The system can be operated by lower-skilled technicians.

COST BREAKDOWN AND TIMELINE

The cost breakdown and timeline are provided in table 3. The cost and time requirements are estimated for the development of the system. The future operation of the system requires no additional cost.

Table 3: Anticipated cost breakdown and timeline of solution implementation.

Task	Anticipated Cost	Anticipated completion time
Task1		
<ul style="list-style-type: none"> Waze data quality report Intersection selection Route creation 	<ul style="list-style-type: none"> Personnel cost Waze data available for free 	Two weeks
Task2		
<ul style="list-style-type: none"> Rea-time data inventory Data management 	<ul style="list-style-type: none"> Personnel Cost Cost for maintaining a database (hard ware cost, database cost etc.) 	<ul style="list-style-type: none"> 3-7 days for initialization on-going for data management
Task3		
<ul style="list-style-type: none"> Delay Computation Identify LOS Identify Suitable Performance Measures 	<ul style="list-style-type: none"> Personnel Cost Communication cost to get TDOT engineers involved in identify measures 	One month
Task4		
<ul style="list-style-type: none"> Automatic Performance Reports Generation 	<ul style="list-style-type: none"> Personnel Cost 	Two weeks to develop the automatic report generation mechanism
Task5: Analysis		
<ul style="list-style-type: none"> Prioritize Corridors Prioritize Signalized intersections Before-After analysis 	<ul style="list-style-type: none"> Personnel Cost 	Two Months

CONCLUSIONS

This proposal first discusses a problem of traffic signal management in Tennessee. Then, system-wide assessment of intersections LOS using Big Data is presented. This approach will eliminate the need for conventional approaches (counting number of vehicles in an intersection or equipping the intersection with counting devices) in travel time delay analysis and deficiency identification. Our method uses Waze data (which is available to TDOT) to calculate travel time and generate performance reports, to help this department facilitate necessary changes in intersections. This can also help TDOT to analyze different corridors to better allocate funding. Finally, based on before after analysis, this solution helps for signal retiming and in a higher level provides a real-time dynamic signal timing. Our proposed approach is easy and cheap to implement anywhere and don't need skilled workers for operation. The data obtained is easy to present and low in error.

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