

Study and Evaluation of IntelliDrive Technology for Traffic Responsive Control Strategies

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ABSTRACT

IntelliDrive is an initiative developed by United States Department of Transportation (USDOT) that aims to enable safe, interoperable networked wireless communications among vehicles, the infrastructure, and passengers' personal communications devices. IntelliDrive technology has the ability to provide data that would be helpful in enhancement of the existing traffic management applications. IntelliDrive data has attributes that cannot be measured using traditional surveillance technology and which can be used for the development of new traffic management and traveler information applications. The traffic responsive plan selection (TRPS) mode of operation is used in coordinated traffic network to improve the performance of the system. This mode of operation has the ability to implement the best possible timing plan for the existing traffic conditions by switching between timing plans. The data from IntelliDrive technology can be utilized in the traffic responsive mode to improve the system performance by reducing the overall delay in the system. This paper proposes a system that can be used to integrate the data obtained from the IntelliDrive technology to the traffic responsive mode of operation. The proposed method utilizes the number of stops and delay of the vehicles in an intersection as a basis for the implementation of the best timing plan for the prevailing traffic condition. The study shows that using the IntelliDrive based TRPS results in the selection of the traffic plan that minimizes the delay of the system and thus results in better system performance compared to the traditional traffic responsive mechanism. The weights that are used in the traditional TRPS mechanism are determined empirically by the traffic engineers, which in many cases lead to erroneous results. With the help of IntelliDrive technology, the delay and the number of stops can be obtained on the field, and the system proposes to use these as the weights. The ultimate aim of any methodology is to decrease the overall delay in the system and by using the delay as the weights, we aim to achieve it.

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DEDICATION

I dedicate this thesis to my husband, Khanjan, whose love, support, patience, and encouragement provided me the strength and perseverance I needed to achieve my goals.

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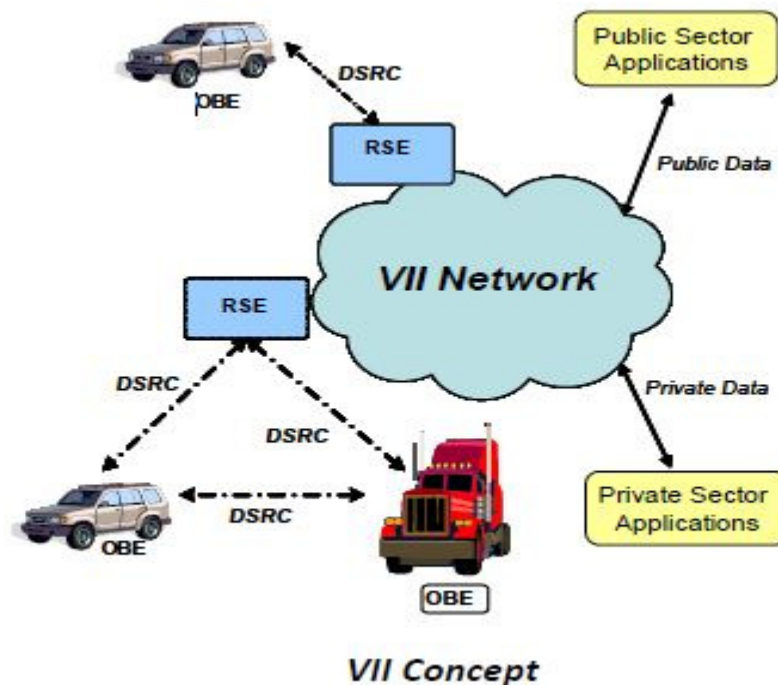
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1. Introduction

The IntelliDrive program (6) is a joint government and industry research effort focused on developing standardized wireless vehicular communications for two primary purposes:

- Vehicle to Vehicle to avoid crashes and to transmit information amongst vehicles
- Vehicle to Infrastructure to collect enhanced roadway condition information and broadcasting various alerts and related traveler information back to vehicles.



Source: Final Report: Vehicle Infrastructure Integration (VII) Proof of Concept (POC) Test – Executive Summary, 2010

Figure 1-1 VII Concept “Used under fairuse guidelines”

With the implementation of the IntelliDrive system, vehicles would be equipped with a dedicated short range communications (DSRC) radio; a highly accurate on board positioning system; and an appropriately configured onboard computer to facilitate communications, support various applications, and provide an interface to the driver (collectively, this equipment is called the onboard equipment—OBE). Vehicles would communicate with each other and with roadside transponders (or roadside equipment—RSE), which would be positioned at major signalized intersections and along interstates and major arterials.

Traffic Responsive Control is a form of adaptive control. It has the ability to switch between different timing plans based on the prevailing traffic states on the field. The main aim of

this type of system is to minimize delay and the number of stops and thus increase the overall system performance.

According to the National Transportation Communications for ITS Protocol (NTCIP), the implementation of the traffic responsive control is done based on two methodologies:

- (i) Threshold mechanism
- (ii) Pattern matching mechanism

Each traffic controller has either one of these methodologies programmed in the system. The underlying theory for these two methodologies is the same but the manner in which the detector data is dealt with is different, i.e. the parameters used in these methodologies are different.

1.1 Thesis Objective

The main objectives of the thesis are:

- To develop algorithm for traffic responsive plan selection (TRPS) system based on IntelliDrive data to optimize traffic operation
- To test the developed algorithm using IntelliDrive data obtained from the Michigan IntelliDrive TestBed.

1.2 Thesis Contribution

This thesis aims at the use of the IntelliDrive technology data with the traditional traffic responsive mode of operation. The data that would be available within the IntelliDrive environment include the position of the vehicle at any given instance of time, the speed of the vehicle at any given instance of time, the acceleration/deceleration of the vehicle amongst other things. Thus, IntelliDrive technology has the potential to provide data that is not available using the traditional technologies and this quality of data would allow the improved use of the existing traffic control system like the TRPS. This thesis focuses on the development of a system which uses the benefits from both the new and the old world technologies.

1.3 Thesis Layout

The thesis is organized into five chapters. Chapter 1 presents an introduction, research objectives, and contribution of the thesis. Chapter 2 presents the literature review for the concepts used. Chapter 3 describes the development of the methodology used for the implementation of the TRPS with the IntelliDrive technology. Chapter 4 describes implementation of the proposed methodology using actual IntelliDrive data from the IntelliDrive Michigan Test Bed. Chapter 5 presents the study conclusions and recommendations for further research.

2. Literature Review

2.1 Overview

Traffic responsive control mode switches timing plans on the field based on the traffic variations. This concept assures applying the most appropriate timing plan for existing traffic pattern which increases the overall system performance by minimizing delay and number of stops. IntelliDrive is an initiative taken by the USDOT which would enable to obtain rich traffic data which were not possible with the use traditional surveillance techniques. Although traffic responsive control mode is efficient and effective, the determination of the weights to be used in the system is done empirically which may lead to erroneous results. The use of the IntelliDrive data would help mitigate this shortcoming of the traditional method. This chapter presents the basics of traffic responsive control and IntelliDrive.

2.2 Traffic Responsive Control Concepts

Like any adaptive mode of control, the traffic responsive mode has the ability to switch between different timing plans to be implemented on the field based on the prevailing traffic states on the field. The main aim of this type of system is to minimize delay and the number of stops and thus increase the overall system performance. Each traffic controller has either the pattern matching or the threshold mechanism methodologies programmed in the system. The underlying theory for these two methodologies is the same but the manner in which the detector data is dealt with is different, i.e. the parameters used in these methodologies are different.

Threshold Mechanism

In this method, the counts and occupancies obtained from each of the detector (i.e. the detector data) is multiplied with the corresponding weight and that forms the computational channel (CC) (4), (5). These computational channel parameters form the plan selection (PS) parameter by aggregation. The plan selection parameters are used to activate the timing plan pre-stored in the controller. Three factors are generally used to aggregate the counts and occupancies obtained from the detectors to the computational channel and plan selection parameters. These factors are:

- (i) **Scaling:** Each system detector has two scaling factors, one for counts and the other for occupancies. The scaling factor helps in converting the individual counts and occupancies value into a combined value from 0-100.
- (ii) **Weighting:** Each detector has a weighting factor which is multiplied to the detector data.
- (iii) **Smoothing:** This is a factor used to eliminate the effect of traffic fluctuations on the data.

The master traffic controller collects the system detector data at regular intervals and calculates the different plan selection parameters. It then compares the calculated plan selection parameters to the ones stored in the controller. When the values of the PS parameter differ as a result of the traffic variations, the master traffic controller switches the timing plan.

Pattern Matching Mechanism

In the pattern matching mechanism (2), (3), (4), the detector data are used in its present condition, i.e. there is no aggregation of the data into CC or PS parameters. There is only one parameter is used, namely the weighting parameter. In this method, the timing plans are switched based on the deviation of the count and occupancy values determined on the field and those stored in the traffic controller.

One of the controllers implementing this mechanism is the 170. The methodology used by the 170 is explained below.

A set of timing plans especially designed for a set of prevailing traffic states are stored in the controller. When a new traffic state is encountered by the controller, it tries to match it to one of the stored states and activate the associated timing plan. This matching is performed by means of the difference in the distance between the existing traffic state and the stored traffic states. System detector count and occupancies are combined together with the pre-programmed counts and occupancies into only one parameter (F_j) for each timing plan. The parameter F_j depends on a global constant for all detectors (K) and a weight factor for each system detector. The formula used to calculate different F_j parameters is (2), (3), (4), (5):

$$F_j = \sum_i | [W_i [(V_i + K * O_i) - (V_{ij} + K * O_{ij})]] |$$

Where,

F_j = summation of the absolute value of the weighted difference between actual detector data and the pre-programmed counts and occupancies associated with each plan over all detectors

V_i and O_i = the measured volumes and occupancies of detector (i), respectively

V_{ij} and O_{ij} = the volumes and occupancies stored with plan (j) for detector (i), respectively

K = a user-specified constant ranging between 0 and 100

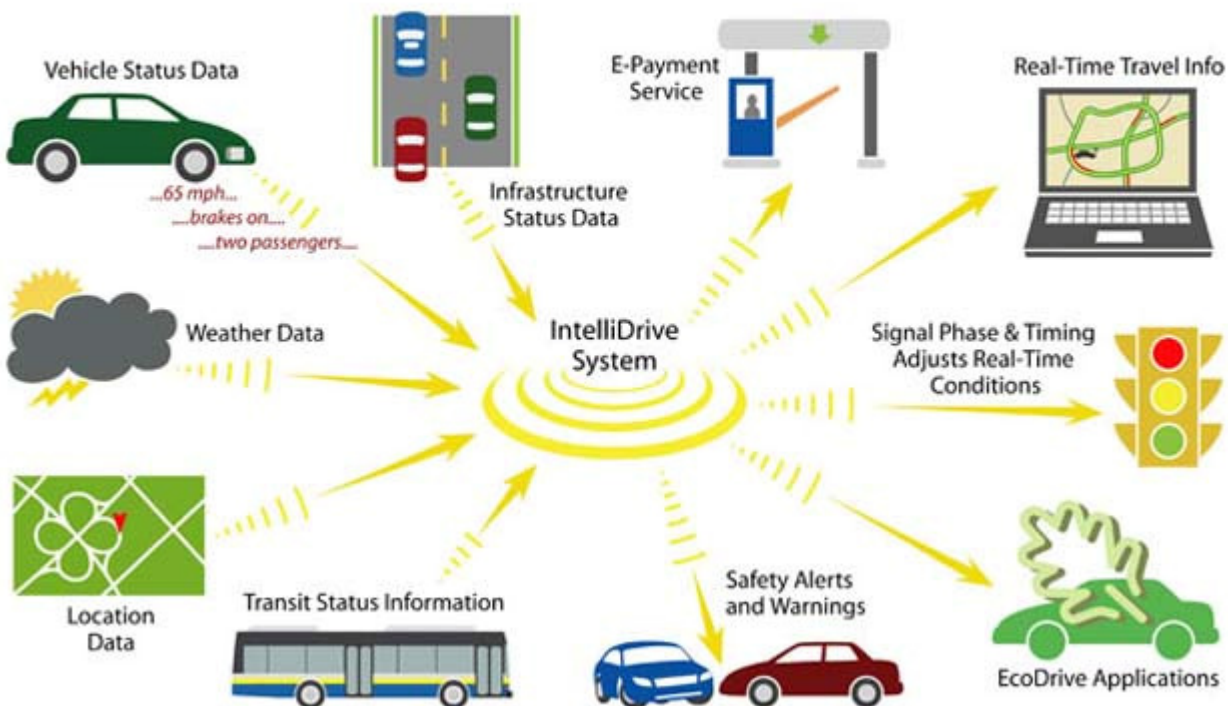
W_i = a detector-specific weighting factor used to emphasize volumes and occupancies measured by selected detectors if their outputs are more important. These values are between 0 and 10.

The master controller selects the minimum of all the F_j values obtained and compares it with the F value of the plan currently in use and if the F_j value is less than the F value of the plan currently in use, the controller switches the timing plan.

2.3 IntelliDrive Concepts

IntelliDrive is a budding technology which has the potential to provide the surface transportation system with the data which would be of significance in improving and supporting traffic management activities (6), (7), and (8). The accessibility of this data would expand and enhance the existing traffic management applications such as signal control, traveler information, travel time calculations, etc). The main advantage of the use of IntelliDrive lies in the fact that it is able to collect data which cannot be obtained with the traditional technologies.

IntelliDriveSM Networked Environment DATA IN, ACTIONABLE INFORMATION OUT



<http://www.thedetroitbureau.com/wp-content/uploads/2010/08/IntelliDrive-chart.jpg> , 2010

Figure 2-1 IntelliDrive Network Environment, “Used under fairuse guidelines”

There are many technological advances in the recent past which have the capability to reform the traditional passive infrastructure-based data collection methods. These technological advancements include the modern communication technology which permits the exchange of data amongst vehicle, travelers, roadside equipments and traffic management systems. These multi-source data streams when used in conjunction with the traditional technologies would have the potential to increase system productivity and traveler mobility significantly while concurrently reducing environmental impacts and increasing safety.

The figure on the next page describes the basic architecture that is used for the IntelliDrive technology. The system, include the onboard equipments (OBE) installed in vehicles. OBEs send and receive messages between each other (for vehicle-to-vehicle applications) and exchange messages with stationary roadside equipments (RSE). The OBEs and RSEs communicate with each other and amongst each other with the help of dedicated short-range communications (DSRC) system. The RSEs are connected to and remotely managed Traffic Management Centers which are used to provide various services to the network and administrative users.

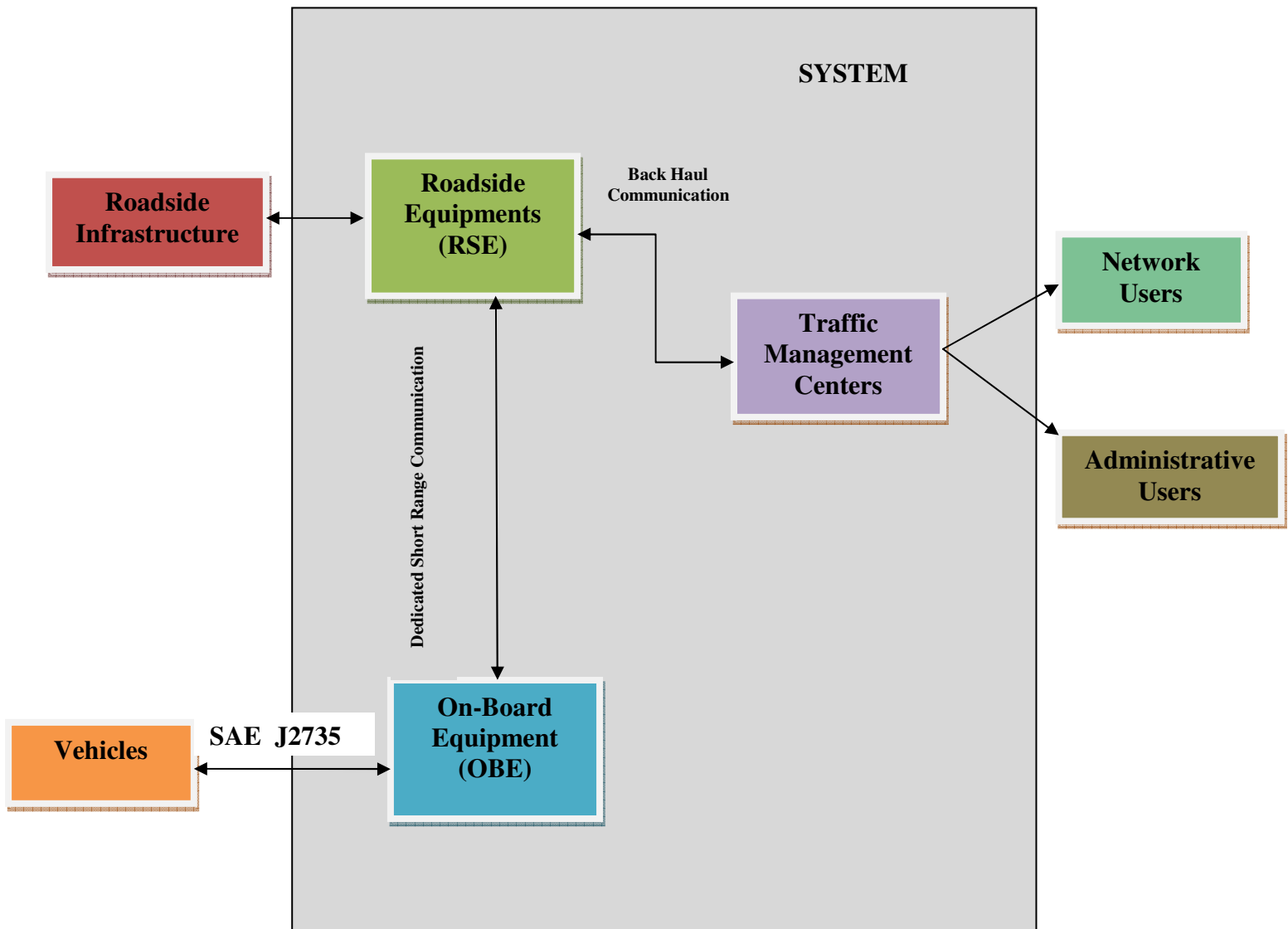


Figure 2-2 IntelliDrive System Architecture

Probe Vehicle Data Protocols

The protocol for the probe vehicle data generation for the IntelliDrive system is developed by the Society of Automotive Engineers (SAE) (11), (12), (13). The J2735 standard defines these types of basic snapshots:

- Periodic snapshot: They are generated to know the condition of vehicles at regular intervals. The general protocol is to generate periodic snapshots based on the speed. Periodic snapshots are generated every 20s for vehicles traveling with speed 60mph or more and every 4s for vehicles travelling with speed less than 20 mph. For vehicles with

speed in between 20 and 60, the snapshots are generated between linearly interpolated intervals.

- Start and stop snapshot: When a vehicle has been recorded with speed 0 for a certain interval (5s is the default), a stop event is generated. In stop-and-go situations, there are chances of recording multiple snapshots are high. To avoid such situations, the stop snapshots are not recorded if a stop has been recorded within the past few seconds. (15s being default). A start snapshot is generated when the speed of the vehicle is above 10mph.
- Snapshot when there are changes in the onboard equipment (OBE)

Snapshot Generation

The generation of periodic and stop/start snapshots are:

- A stop event occurs after a vehicle has been immobilized for at least 5 s if no other stop has been observed in the past 15 s.
- A start event occurs when a vehicle currently assumed to be stopped increases its speed above 10 mph.
- Periodic snapshots are by default generated at intervals based on the speed of the vehicle. A snapshot would be generated every 20 s at speeds above 60 mph, every 4 s at speeds below 20 mph, and at linearly interpolated intervals for speeds in between.
- Periodic snapshot collection is to be suspended when a vehicle is stopped.

Working of OBEs

The vehicle's onboard equipment acts as a buffer and stores the snapshots that are generated till they can be transmitted to roadside equipment (13), (14), (15). The snapshots are stored in the order in which they are generated but the method of retrieval of the periodic and the start/stop snapshots is different. The start/stop snapshots have a priority in retrieval over the periodic snapshots. If the OBE's buffer becomes full, the second last periodic snapshot would be removed to be able to include new periodic and/or start/stop snapshot. The reason for removing the second last snapshot rather than the last snapshot is that the last snapshot would be useful in obtaining the information about the time and the distance traveled since the last data upload.

Privacy Issues

There are rules which prohibit the tracking of a vehicle over a long distance. Thus there is a special tracking number known as the Probe Sequence Number (PSN) which would be randomly generated and make it possible to obtain the travel information without knowing the identity of a particular vehicle. The PSN changes when:

- The vehicle has traveled for 1000m or 120s (whichever comes last) with the same PSN. These thresholds allow the tracking of the vehicle over a distance which is comparable with a distance for a standing observer who collects the data.
- After snapshots with a specific PSN have been uploaded by an RSE, other snapshots subsequently generated with the same PSN cannot be uploaded at other RSEs. This rule

is imposed to remove the ability of tracking vehicle movements from one RSE to the next.

- Termination of a connection with an RSE will automatically trigger a change of PSN. This rule enforces the previous one by ensuring that specific PSN are used at only one RSE. It notably allows reducing potential snapshot losses that would arise if vehicles were allowed to keep using a given PSN following termination of a RSE connection.
- The PSN is also automatically changed when the memory buffer of a vehicle becomes empty. This typically occurs after a vehicle has terminated sending all snapshots stored within the buffer following the establishment of a communication link with a RSE. This rule was again designed to reduce potential snapshot losses that would arise if vehicles were allowed to keep using a given PSN following termination of a RSE connection.

Following a PSN change, all snapshots generated during a randomly determined interval of 3 to 13 s, or 164 to 820 ft (50 to 250 m), whichever occurs first, are discarded. This rule is imposed to make it difficult to try to track vehicle movements by attempting to use data recorded within each snapshot to logically link sequences of snapshots with different PSNs. Vehicle anonymity is further enforced by requiring probe vehicle snapshots to hold no information that could be used to link the snapshots to a particular vehicle.

Working of RSEs

A communication link is established after the vehicle comes in range of an RSE. The theoretical communication range for a RSE is 3200 ft but the actual implementation on the field indicates that the communication range is around 1300 to 1600 ft (13), (14), (15). The upload process starts after the communication link has been established. The information from the vehicle's buffer is transmitted in form of a message which contains up to four snapshots with each of the snapshot with the same RSE.

3. IntelliDrive Application in Traffic Responsive Control

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ABSTRACT

The IntelliDrive technology has the ability to provide data that would be helpful in enhancement of the existing traffic management applications. IntelliDrive data has attributes that cannot be measured using traditional surveillance technology and which can be used for the development of new traffic management and traveler information applications. The traffic responsive plan selection (TRPS) mode of operation is used in coordinated traffic network to improve the performance of the system. This mode of operation has the ability to implement the best possible timing plan for the existing traffic conditions by switching between timing plans. The data from IntelliDrive technology can be utilized in the traffic responsive mode to improve the system performance by reducing the overall delay in the system. This paper proposes a system, Virginia Tech Intelli-TRPS, that can be used to integrate the data obtained from the IntelliDrive technology to the traffic responsive mode of operation. The Intelli-TRPS utilizes the number of stops and delay of the vehicles in an intersection as a basis for the implementation of the best timing plan for the prevailing traffic condition. The study shows that using the IntelliDrive based TRPS results in the selection of the traffic plan that minimizes the delay of the system and thus results in better system performance compared to the traditional traffic responsive mechanism.

Keywords- Traffic Responsive, VII, IntelliDrive, Signal Control, VISSIM

3.1 Introduction

Traffic Responsive Plan Selection (TRPS) mode of operation is used in a coordinated traffic network to improve the performance of the system. This method has the ability to switch between timing plans based on the traffic conditions. According to The National Transportation Communications for ITS Protocol (NTCIP) 1210 field management stations document (1), two different methodologies are followed to implement traffic responsive control in any traffic network: the first is threshold mechanism, and the second is pattern matching mechanism. Each controller manufacturer provides one of those methodologies in their traffic controllers to implement traffic responsive control mode of operation. The concept for these two methodologies is the same but the way to deal with detector data is different.

Threshold Mechanism

In order to implement the threshold mechanism, the detector counts and occupancies are multiplied by a set of weights defined by the traffic engineer to form the computational channel (CC) parameters. The CC parameters are then combined to form the plan selection (PS) parameters that are used to implement a timing plan pre-stored in the master controller. The master controller collects the system detector data, calculates the PS parameters and compares the PS parameters obtained to the predefined set of threshold. The values of PS change with the traffic patterns, which cause the controller to switch between timing plans.

Pattern Matching Mechanism

In pattern matching mechanism, the detector counts and occupancies are used to identify the different traffic states. A set of timing plans especially designed for a set of prevailing traffic states are stored in the controller. When a new traffic state is encountered by the controller, it tries to match it to one of the stored states and activate the associated timing plan. This matching is performed by means of the difference in the distance between the existing traffic state and the stored traffic states. System detector count and occupancies are combined together with the pre-programmed counts and occupancies into only one parameter (F_j) for each timing plan. The parameter F_j depends on a global constant for all detectors (K) and a weight factor for each system detector. The formula used to calculate different F_j parameters is (2), (3), (4), (5):

$$F_j = \sum_i \left| \left| W_i [(V_i + K * O_i) - (V_{ij} + K * O_{ij})] \right| \right| \quad (1)$$

Where,

- F_j = summation of the absolute value of the weighted difference between actual detector data and the pre-programmed counts and occupancies associated with each plan over all detectors
- V_i and O_i = the measured volumes and occupancies of detector (i), respectively
- V_{ij} and O_{ij} = the volumes and occupancies stored with plan (j) for detector (i), respectively

- K = a user-specified constant ranging between 0 and 100
- W_i = a detector-specific weighting factor used to emphasize volumes and occupancies measured by selected detectors if their outputs are more important. These values are between 0 and 10.

The master controller selects the minimum of all the F_j values obtained and compares it with the F value of the plan currently in use and if the F_j value is less than the F value of the plan currently in use, the controller switches the timing plan.

IntelliDrive

The IntelliDrive (previously known as Vehicle Infrastructure Integration, VII) program focuses on the development of a wireless communication between vehicle-to-vehicle and vehicle-to-infrastructure for the overall improvement of the traffic system (5). In an IntelliDrive environment, the vehicles would be equipped with a dedicated short-range communications (DSRC) radio, a highly accurate on-board positioning system and on-board equipment (OBE) which would provide an interface to the driver. The roadside equipment (RSE) would communicate with the vehicles through the wireless devices to provide continuous real-time connectivity to all system users which would enable safety, mobility and environmental benefits.

The data that would be available within the IntelliDrive environment include the position of the vehicle at any given instance of time, the speed of the vehicle at any given instance of time, the acceleration/deceleration of the vehicle. Thus, IntelliDrive technology has the potential to provide data that is not available using the traditional technologies and this quality of data would allow the improved use of the existing traffic control system like the TRPS.

Among the two TRPS mechanism, the pattern matching mechanism has a greater potential to differentiate between the timing plans and to implement the timing plan closest to the existing system (4). One of the drawbacks of the existing pattern matching system is that the detector weights (W) that are provided are based on empirical analysis of the traffic engineers. The performance measures, i.e. the delay and the number of stops, are not taken into consideration when selecting the timing plan that is to be implemented. Also, the existing system makes use of the data that is based on the deployment of the infrastructure based sensors which detect the data passively (7). In contrast to this, the data from the IntelliDrive environment is more robust and has the ability to provide vehicle speed and location in real time. The speed and the location of the vehicle can be used to determine the number of stops and delay experienced by the vehicle on the field (8), (9), (10). The delay and the number of stops obtained in the field can be used as a measure to implement the TRPS mechanism. The number of stops made by vehicles is an important measure of quality of traffic flow progression. While reducing the number of stops usually leads to a reduction in incurred delay, fewer stops also often lead to reduced fuel consumption and vehicle emission. The delay experienced by drivers while traveling on a section of road is commonly used to assess quality of travel. The quality of services reduces with the increase in delay. At signalized intersections, the delay is further used to quantify the impacts on traffic flow operations of traffic interruptions imposed by red signals and gap seeking turn maneuvers (8), (10).

A lot of research has been done on the collection methods of the IntelliDrive data and the use of that data for safety applications. One of the major researches of IntelliDrive data is for the collision avoidance system (19). The signal control is an area which is still under-developed in the IntelliDrive world. Now, with the clear knowledge of all the data that can be obtained with the use of this technology (8), (9), it is possible to implement it in the traffic signal controls. The study presented here aims at bridging the gap between the traditional traffic responsive methodologies with the use of the upcoming IntelliDrive technology. This study provides a methodology that makes use of delay and number of stops data to implement the traffic responsive plan selection.

3.2 Virginia Tech Intelli-TRPS

For the implementation of TRPS in IntelliDrive environment, the main weighting parameters that are proposed are the performance factors delay and the number of stops of the system. With the use of IntelliDrive technology, the delay and stops can be obtained on the field. The proposed system makes use of the data that is available in the field as the weights to determining the selection of the timing plan without any assumptions. The following ways are used to determine the delay and the number of stops.

Delay (T)

The actual arrival time of a vehicle to the intersection can be calculated as the difference between the ideal arrival time calculated with the speed measured at 400 feet from the intersection (assuming there is no control effect at that distance) and the actual arrival time of the vehicle. The delay for all the vehicles present within the 400 ft distance of the intersection for each movement is summed up to calculate the total delay for the movement.

Number of stops (S)

IntelliDrive enabled probe vehicles generate start and stop snapshots based on SAE J2735 standards. These standards are based on the current vehicle speed and duration of slow speed travel by vehicles. A stop snapshot is generated when a vehicle registers a current speed of 0 mph for consecutive seconds exceeding the stop threshold (default = 5 seconds). After a stop snapshot is created, a start snapshot will be generated if the current vehicle speed exceeds a start threshold (default = 10 mph). Multiple stop snapshots might be generated when there is an extended stop of 30 or more seconds. To avoid this, the rate of production of stop snapshots is limited by a stop lag parameter (default = 15 seconds), which is the minimum time between stop snapshots with no intervening start snapshot (11), (12), (13).

When a VII snapshot is generated, it is stored in-vehicle (on the VII on-board equipment, or OBE) until it is either transmitted to an RSE encountered later or deleted because of finite storage capacity in the OBE for snapshot data. When a VII-enabled probe vehicle is within range of an RSE, it transmits all of the snapshots stored on the OBE. Transmission occurs instantaneously at the *transmit range* of 400 feet or closer to the RSE, regardless of the number of vehicles transmitting probe data at that moment. The information from each of the vehicle is sent to the RSE where it is aggregated for all the vehicles on each of the movements in that intersection (13), (14), (15).

The formulation used to calculate the F parameter to determine which timing plan is to be selected is shown below:

$$F_j = \sum_t \sum_i |[\beta_t(S_{it} + \alpha T_{it}) * (V_i - V_{ij})]| \quad (2)$$

Where,

- F_j = sum over all movements (i) of the absolute value of the weighted difference between actual field data and the pre-programmed stops and delay accompanied with each plan.
- S_{it} = the calculated number of stops for movement i per vehicle over time t
- T_{it} = the calculated delay for movement i per vehicle over time t
- α = a user defined constant between 0 and 100 to have the stops and wait time in the same units
- β_t = a factor to average the weights over time t
- V_i = the total volume for the movement i
- V_{ij} = the volume associated with plan j and movement i

The above formula would provide the distance between the existing traffic state and the traffic state that corresponds to the stored timing plans. The minimum distance F_j is selected and the corresponding timing plan is implemented. The formula takes into account the stops, delay and the volume of the current traffic state on the field and the volume of the traffic states stored in the controller. Figure 1 is the spatial representation of the traffic states and the timing plans (the F_{iz} is not shown in the figure to reduce clutter). The three circles represent the three traffic states, traffic state 1 (TS1), traffic state 2 (TS2) and traffic state 3 (TS3) stored in the controller corresponding to the three different timing plans, timing plan 1 (TP1), timing plan 2 (TP2) and timing plan 3 (TP3) respectively. The three timing plans are represented on the X, Y and Z axes. The triangle represents the current traffic state for which the corresponding traffic state is to be determined. This is done by finding the distance between the stored traffic states and the existing traffic states using the distance formula.

$$F_i = \sqrt{F_{ix}^2 + F_{iy}^2 + F_{iz}^2} \quad (3)$$

The timing plan corresponding to the minimum F value i.e. the minimum distance would be the selected timing plan for the current traffic state.

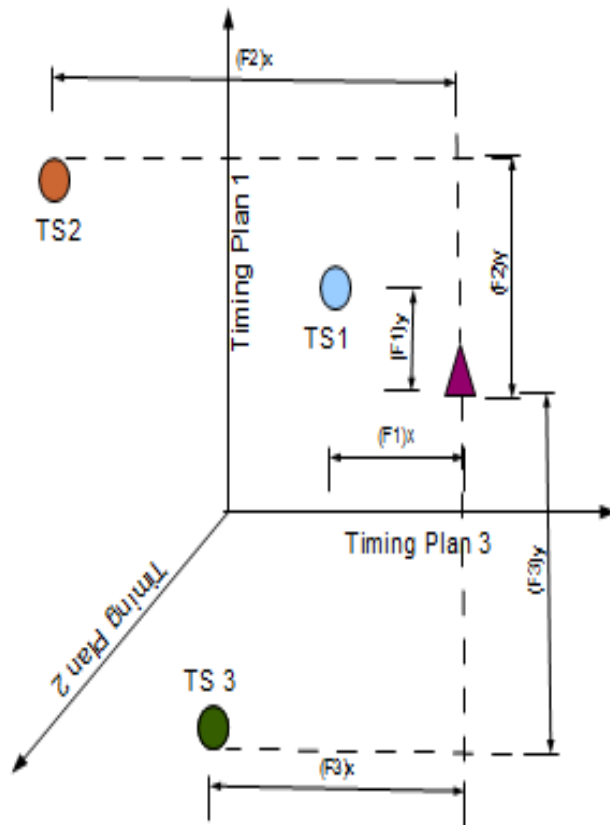


Figure 3-1 Spatial representation of Traffic States with Traffic Plans

3.3 Implementation

For implementing Intelli-TRPS, the data from the Reston Parkway arterial in Northern Virginia were used. 5 intersections were considered for the study (shown in Figure 2). The speed limit for the main arterial is 45mph and is 25 mph or 35 mph for the side streets.

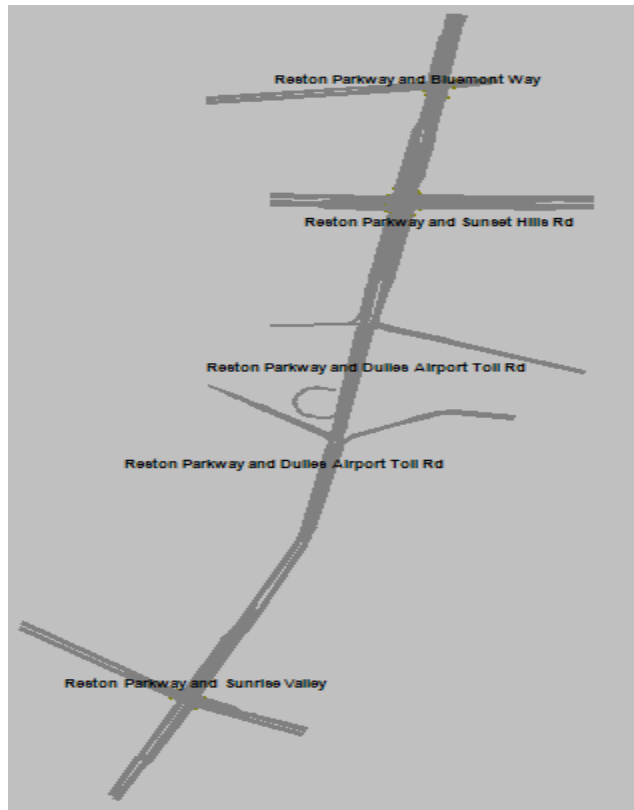


Figure 3-2 Reston Parkway

Five traffic scenarios were considered, with varying traffic volumes. The distribution of the volumes over the 8 movements corresponding to each of the traffic state is shown in Table 4-1. The movements are the 8 phases of a NEMA ring and barrier diagram. PASSER V optimization package (17) was used to generate different timing plans. Five best timing plans (based on minimum delay), one corresponding to each scenario, were selected out of the several timing plans generated. The timing plans selected had a cycle length of 70 sec, 155 sec, 160 sec, 105 sec and 135 sec.

The volume data for the five traffic scenarios was fed into the VISSIM simulation package. Each scenario was simulated with each of the timing plans and the results were recorded. The delay and the number of stops were calculated in a manner described above. The values of the number of stops (S) and the delay (T) are shown in Table 4-2 and Table 4-3 respectively.

For checking the performance of the TRPS system, three new traffic states were considered. The traffic states were chosen in a way that the volumes and delay obtained from those traffic states were different from the five traffic states that are stored in the controller. This was done to represent the actual field conditions. On the field, there would seldom be a situation where the prevailing traffic conditions would be exactly same as the traffic states that are stored in the controller. The volumes of the newly considered traffic states are shown in the Table 3-4. The F_j values for each of the traffic states was calculated and compared to the timing plans. For traffic states 1 through 5, the minimum F_j values were obtained corresponding to the timing plans 1 through 5 respectively. For traffic state 6, the minimum F_j value obtained corresponded

to timing plan 2, for traffic state 7, the minimum F_j value was obtained corresponding to timing plan 5 and for traffic state 8, the minimum F_j value was obtained corresponding to traffic state 1.

Traffic States	1	2	3	4	5	6	7	8
1	0	7	5	12	0	55	12	48
2	276	1800	276	1785	733	3622	473	3836
3	687	2840	723	2548	894	3984	845	4428
4	528	576	212	996	844	1086	408	1085
5	48	224	56	190	126	298	38	438

Table 3-1 Volumes corresponding to the different traffic states

Timing Plan	1	2	3	4	5	6	7	8
1	0	1	0	1	0	0	1	0
2	5	7	6	5	7	7	5	7
3	5	4	4	1	4	4	4	8
4	6	7	5	4	7	1	3	3
5	1	1	2	3	6	3	1	1

Table 3-2 Number of stops (S) for different timing plans corresponding to the different movements for the proposed system

Timing Plan	1	2	3	4	5	6	7	8
1	0	0	0	0	0	0	0	1
2	4	3	3.3	4	5	6.5	3	4
3	6	4.5	2	5	2	5.4	2	6
4	4	4	1	3	6.2	6	1	3
5	2	3	4	4	4	2	2	1

Table 3-3 Delay (T) for different timing plans corresponding to the different movements for the proposed system

Traffic States	1	2	3	4	5	6	7	8
6	523	1082	523	2004	745	3276	451	3821
7	27	198	48	150	102	256	28	418
8	7	6	10	21	8	40	7	12

Table 3-4 Volumes Corresponding to the new Traffic States

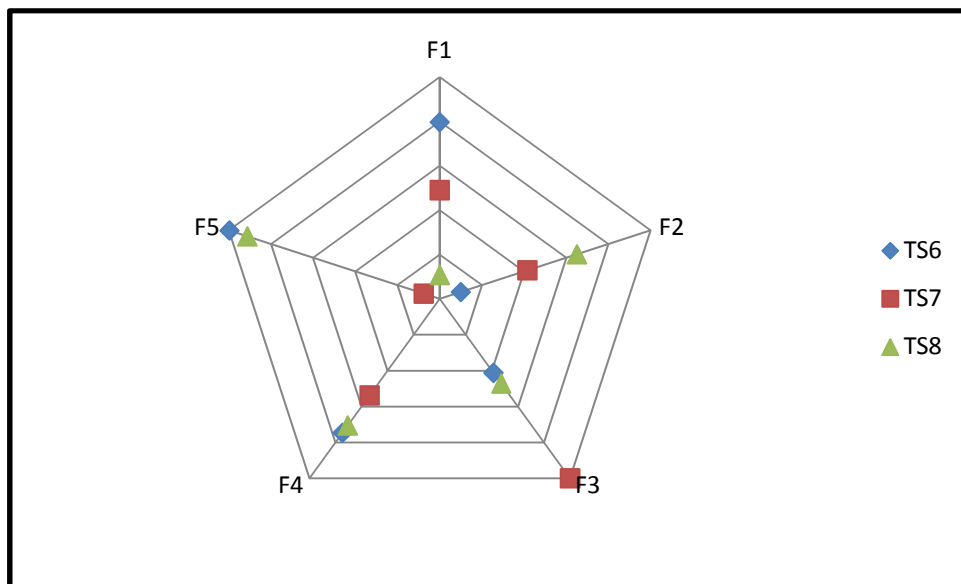


Figure 3-3 Determination of the minimum F value

The Figure 3-3 shows how the best timing plan is determined by finding out the minimum F values corresponding to each traffic state by the system. F1, F2, F3, F4, and F5 are the F values corresponding to timing plans 1 through 5 respectively calculated using formula (2). The aim of the system is to find the minimum F value corresponding to each traffic state and timing plan. As Intelli-TRPS uses the stops and delay to calculate the F value, the minimum F value would mean the minimum stops and delay. In this figure, the diamond, square and the triangle represent the three traffic states for which the timing plans have to be determined (traffic states 6, 7 and 8). The center of the web corresponds to the F value equal to 0. Thus, the closer the traffic state is to the center of the web, the lower the F value of that state. Thus, we can find out the minimum F value for each state and determine the corresponding timing plan.

To verify whether the timing plans selected by the above method were correct, each of the three new traffic states was simulated in VISSIM (17) with all the five timing plans. Figure 4 shows the delays that were obtained when the different traffic states were simulated with the different timing plans in VISSIM. As we can see from the graph, the minimum delay for traffic state 6 corresponds to timing plan 2. Similarly, for traffic state 7, the minimum delay is obtained when plan 5 is selected and timing plan 1 provides minimum delay for traffic state 8. The timing plans that are selected by the system are the same as the once obtained using VISSIM. Thus, it can be inferred that the use of this system results in the selection of the timing plan which provides the minimum delay.

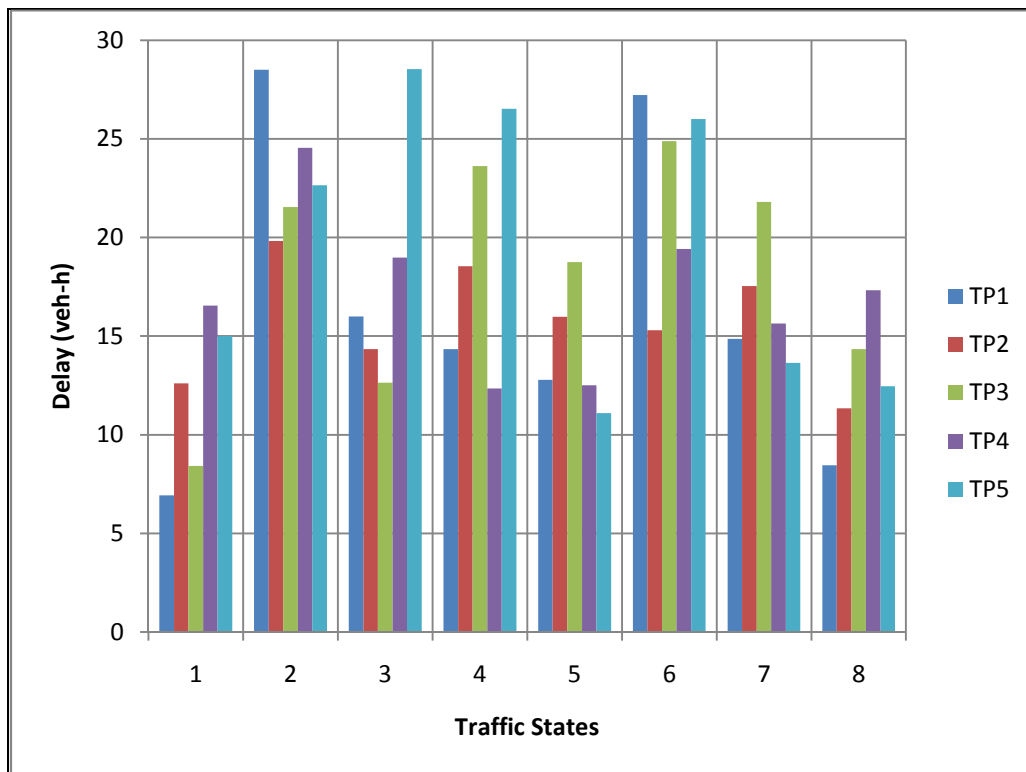


Figure 3-4 Delay for the combination of different traffic states and timing plans

3.4 Comparison with current pattern matching mechanism

In order to compare the proposed system with the existing system, the same traffic data was used and the timing plans were selected based on the traditional pattern matching TRPS method.

The detector count and occupancy data from the field for five traffic scenarios were directly used to conduct the pattern matching method. Different weights were assigned to the eight system detectors (movements in our case). They are shown in Table 3-5. The K factor used in our case is 50%. The F_j was calculated using equation 1 and the minimum F_j was matched with the corresponding timing plans. For states 1, through 5 the corresponding timing plans

obtained were 1 through 5 respectively. For the traffic state 6, the plan that was selected by this method was plan 3. As seen from the VISSIM simulation result (Figure 3), the timing plan which provided the minimum delay for the traffic state 6 was plan 2. For the traffic state 7, the traditional TRPS mechanism gave the minimum F_j corresponding to timing plan 5 which as we can see from the graph above, is the timing plan which would yield minimum delay. For the final traffic state, 8, which corresponded to timing plan 1, traditional TRPS method gave the minimum F_j value corresponding to the timing plan 5. Table 3-6 shows the actual delay for that state obtained using VISSIM, the delay obtained by the timing plan selected by traditional TRPS mechanism, the delay obtained by the timing plan selected using the IntelliDrive based TRPS and the percentage error in delay obtained when using the traditional TRPS mechanism for the three new traffic states that are not stored in the controller. From the table we can see that using the IntelliDrive based data would result in a decrease in the overall system delay by almost 55%. The error in the results when using the traditional TRPS mechanism can be attributed to the detector weights. As mentioned above, there is no fixed rule that is used to determine the weights given to the detectors. The weights are provided at the discretion of the traffic engineer and there might be cases where the weights are wrongly assigned which would lead to the improper functioning of the system.

As the results indicate, the traditional TRPS mechanism selects the correct timing plan when the prevailing traffic states on the field match the traffic states stored in the controller. When the prevailing and the stored traffic state differ, the selection of the traffic state relies heavily on the weights that are assigned to the detectors. As there are no set rules for the determination of the weights and they are solely based on the experience and the observation of the traffic engineer, there are chances that the weights assigned are incorrect. This would lead to the selection of erroneous timing plan which would in turn result in the increase in delay of the system. The availability of the IntelliDrive data provides us the ability to utilize the performance measures as the input data for the calculation of optimized timing plan. With the use of delay and stops as the input data, it is possible to select a timing plan which would minimize the input, i.e. the delay and the number of stops in the system. The aim of optimizing any traffic signal is to improve the system by minimizing the total delay and the number of stops. The results here show that the use of the IntelliDrive based data can lead to a decrease in the total system delay by almost 55% which would be a significant improvement.

Movement	1	2	3	4	5	6	7	8
Weights	9	2	1	3	2	9	3	4

Table 3-5 Weights (s) for traditional TRPS

Traffic State	Timing Plan selected using traditional TRPS	Timing plan selected using IntelliDrive based TRPS	Delay with traditional TRPS	Delay with IntelliDrive based TRPS	% Improvement
6	3	2	24.887	15.3	62.66
7	5	5	17.458	17.458	0
8	5	1	12.46	8.45	47.45

Table 3-6 Delay using both the methods

3.5 Conclusion

This paper proposes a method that can be used to integrate the current traffic responsive mode of operation with the upcoming IntelliDrive technology. Five intersections of the Reston Parkway arterial were considered for this study and the current TRPS mechanism was compared with the proposed IntelliDrive based traffic responsive mechanism. It was found that the Intelli-TRPS performed better in selecting the plan which would reduce the system delay. Using the data obtained from IntelliDrive technology, it is possible to compute the total delay and number of stops encountered by each vehicle on the field and thus these parameters can be directly used to compute the best available timing plan for the existing traffic scenario. The study shows that using the Intelli-TRPS results in the selection of the traffic plan that reduces the delay of the system by 55% compared to the traditional TRPS mechanism. According to the USDOT, if IntelliDrive data improves signal operation by 10 percent, it would save an estimated 1.7 million hours of delay, 1.1 million gallons of gasoline, and 9,600 tons of CO₂ emissions a year, at full deployment (18).

Future work includes the implementation of this system in the entire network for a weekday and weekend. This would give us an opportunity to study many traffic scenarios with many different plans. Other than this, to further study the effectiveness of the proposed system, the volumes of the traffic can be changed only on the main street keeping the volumes on the side street unchanged and then only on the side streets to understand this change in the traffic pattern. Also, the working of the system at different market share rates would be seen in the future work.

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4. Evaluation of Intelli-TRPS Algorithm using Michigan IntelliDrive Data

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4.1 Introduction

The IntelliDrive technology provides vehicles the ability to communicate wirelessly with the road side equipments and aims at providing safety and mobility enhancements. This would be of advantage to the transportation system operators as it would be possible to obtain information such as travel time, speed and positions of the vehicles from each of the vehicle equipped with this technology

Traffic Responsive Plan Selection (TRPS) mode of operation is used in a coordinated traffic network to improve the performance of the system. This method has the ability to switch between timing plans based on the traffic conditions. According to The National Transportation Communications for ITS Protocol (NTCIP) 1210 field management stations document (1), two different methodologies are followed to implement traffic responsive control in any traffic network: the first is threshold mechanism, and the second is pattern matching mechanism. Each controller manufacturer provides one of those methodologies in their traffic controllers to implement traffic responsive control mode of operation. The concept for these two methodologies is the same but the way to deal with detector data is different.

The Intelli-TRPS (20) methodology developed by Virginia Tech, takes advantage from both the traditional TRPS method and the data available from IntelliDrive. It uses the delay and stops obtained with from IntelliDrive as weights in the TRPS mechanism. The resulting method is more robust and optimal in selecting the timing plan to be implemented on the field and reduces the overall delay in the system.

Threshold Mechanism

In order to implement the threshold mechanism, the detector counts and occupancies are multiplied by a set of weights defined by the traffic engineer to form the computational channel (CC) parameters. The CC parameters are then combined to form the plan selection (PS) parameters that are used to implement a timing plan pre-stored in the master controller. The master controller collects the system detector data, calculates the PS parameters and compares the PS parameters obtained to the predefined set of threshold. The values of PS change with the traffic patterns, which cause the controller to switch between timing plans.

Pattern Matching Mechanism

In pattern matching mechanism, the detector counts and occupancies are used to identify the different traffic states. A set of timing plans especially designed for a set of prevailing traffic states are stored in the controller. When a new traffic state is encountered by the controller, it tries to match it to one of the stored states and activate the associated timing plan. This matching is performed by means of the difference in the distance between the existing traffic state and the stored traffic states. System detector count and occupancies are combined together with the pre-programmed counts and occupancies into only one parameter (F_j) for each timing plan. The parameter F_j depends on a global constant for all detectors (K) and a weight factor for each system detector. The formula used to calculate different F_j parameters is (2), (3), (4), (5):

$$F_j = \sum_i | [W_i[(V_i + K * O_i) - (V_{ij} + K * O_{ij})]] | (1)$$

Where,

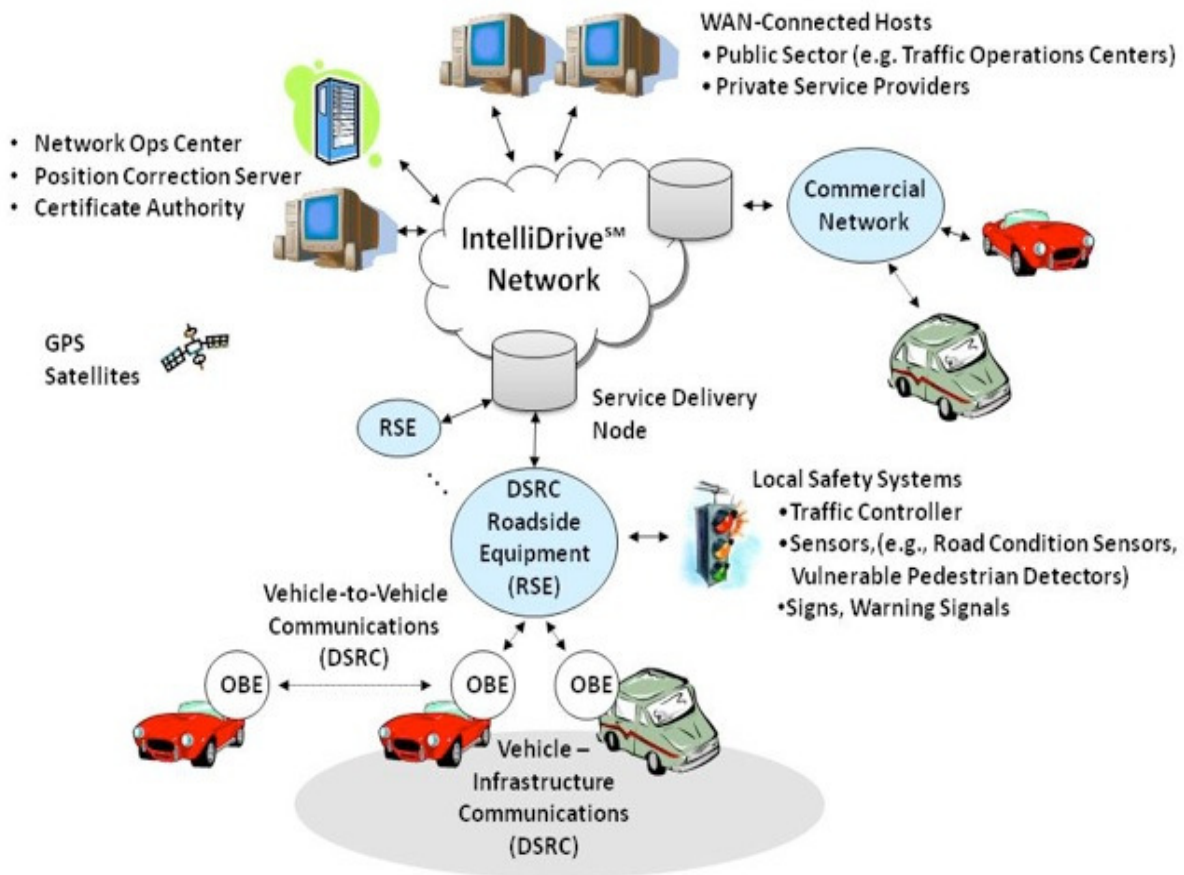
- F_j = summation of the absolute value of the weighted difference between actual detector data and the pre-programmed counts and occupancies associated with each plan over all detectors
- V_i and O_i = the measured volumes and occupancies of detector (i), respectively
- V_{ij} and O_{ij} = the volumes and occupancies stored with plan (j) for detector (i), respectively
- K = a user-specified constant ranging between 0 and 100
- W_i = a detector-specific weighting factor used to emphasize volumes and occupancies measured by selected detectors if their outputs are more important. These values are between 0 and 10.

The master controller selects the minimum of all the F_j values obtained and compares it with the F value of the plan currently in use and if the F_j value is less than the F value of the plan currently in use, the controller switches the timing plan.

IntelliDrive

The IntelliDrive (previously known as Vehicle Infrastructure Integration, VII) program focuses on the development of a wireless communication between vehicle-to-vehicle and vehicle-to-infrastructure for the overall improvement of the traffic system (5). In an IntelliDrive environment, the vehicles would be equipped with a dedicated short-range communications (DSRC) radio, a highly accurate on-board positioning system and on-board equipment (OBE) which would provide an interface to the driver. The roadside equipment (RSE) would communicate with the vehicles through the wireless devices to provide continuous real-time connectivity to all system users which would enable safety, mobility and environmental benefits.

The data that would be available within the IntelliDrive environment include the position of the vehicle at any given instance of time, the speed of the vehicle at any given instance of time, the acceleration/deceleration of the vehicle. Thus, IntelliDrive technology has the potential to provide data that is not available using the traditional technologies and this quality of data would allow the improved use of the existing traffic control system like the TRPS. The Intelli-TRPS methodology developed takes advantage of this data and results in a more efficient system by reducing overall delay in the system as compared to the traditional TRPS system .



http://itsinsight.com/IntelliDrive_files/droppedImage.jpg, 2010

Figure 4-1 Working of IntelliDrive System “Used under fairuse guidelines”

Among the two TRPS mechanism, the pattern matching mechanism has a greater potential to differentiate between the timing plans and to implement the timing plan closest to the existing system (4). One of the drawbacks of the existing pattern matching system is that the detector weights (W) that are provided are based on empirical analysis of the traffic engineers. The performance measures, i.e. the delay and the number of stops, are not taken into consideration when selecting the timing plan that is to be implemented. Also, the existing system makes use of the data that is based on the deployment of the infrastructure based sensors which detect the data passively (7). In contrast to this, the data from the IntelliDrive environment is more robust and has the ability to provide vehicle speed and location in real time. The speed and the location of the vehicle can be used to determine the number of stops and delay experienced by the vehicle on the field (8), (9), (10). The delay and the number of stops obtained in the field

can be used as a measure to implement the TRPS mechanism. The number of stops made by vehicles is an important measure of quality of traffic flow progression. While reducing the number of stops usually leads to a reduction in incurred delay, fewer stops also often lead to reduced fuel consumption and vehicle emission. The delay experienced by drivers while traveling on a section of road is commonly used to assess quality of travel. The quality of services reduces with the increase in delay. At signalized intersections, the delay is further used to quantify the impacts on traffic flow operations of traffic interruptions imposed by red signals and gap seeking turn maneuvers (8), (10).

Probe Vehicle Data Protocols

The protocol for the probe vehicle data generation for the IntelliDrive system is developed by the Society of Automotive Engineers (SAE). The J2735 standard defines these types of basic snapshots:

- Periodic snapshot
- Start and stop snapshot
- Snapshot when there are changes in the onboard equipment (OBE)

Snapshot Generation

The generation of periodic and stop/start snapshots are:

- A stop event occurs after a vehicle has been immobilized for at least 5 s if no other stop has been observed in the past 15 s.
- A start event occurs when a vehicle currently assumed to be stopped increases its speed above 10 mph.
- Periodic snapshots are by default generated at intervals based on the speed of the vehicle. A snapshot would be generated every 20 s at speeds above 60 mph, every 4 s at speeds below 20 mph, and at linearly interpolated intervals for speeds in between.
- Periodic snapshot collection is to be suspended when a vehicle is stopped.

Working of OBEs

The vehicle's onboard equipment acts as a buffer and stores the snapshots that are generated till they can be transmitted to roadside equipment. The snapshots are stored in the order in which they are generated but the method of retrieval of the periodic and the start/stop snapshots is different. The start/stop snapshots have a priority in retrieval over the periodic snapshots. If the OBE's buffer becomes full, the second last periodic snapshot would be removed to be able to include new periodic and/or start/stop snapshot. The reason for removing the second last snapshot rather than the last snapshot is that the last snapshot would be useful in obtaining the information about the time and the distance traveled since the last data upload.

Privacy Issues

There are rules which prohibit the tracking of a vehicle over a long distance. Thus there is a special tracking number known as the Probe Sequence Number (PSN) which would be randomly generated and make it possible to obtain the travel information without knowing the identity of a particular vehicle. The PSN changes when:

- The vehicle has traveled for 1000m or 120s (whichever comes last) with the same PSN
- The vehicle uploaded all the stored information to a RSE
- A connection with the RSE was lost

Working of RSEs

A communication link is established after the vehicle comes in range of an RSE. The theoretical communication range for a RSE is 3200 ft but the actual implementation on the field indicates that the communication range is around 1300 to 1600 ft. The upload process starts after the communication link has been established. The information from the vehicle's buffer is transmitted in form of a message which contains up to four snapshots with each of the snapshot with the same RSE.

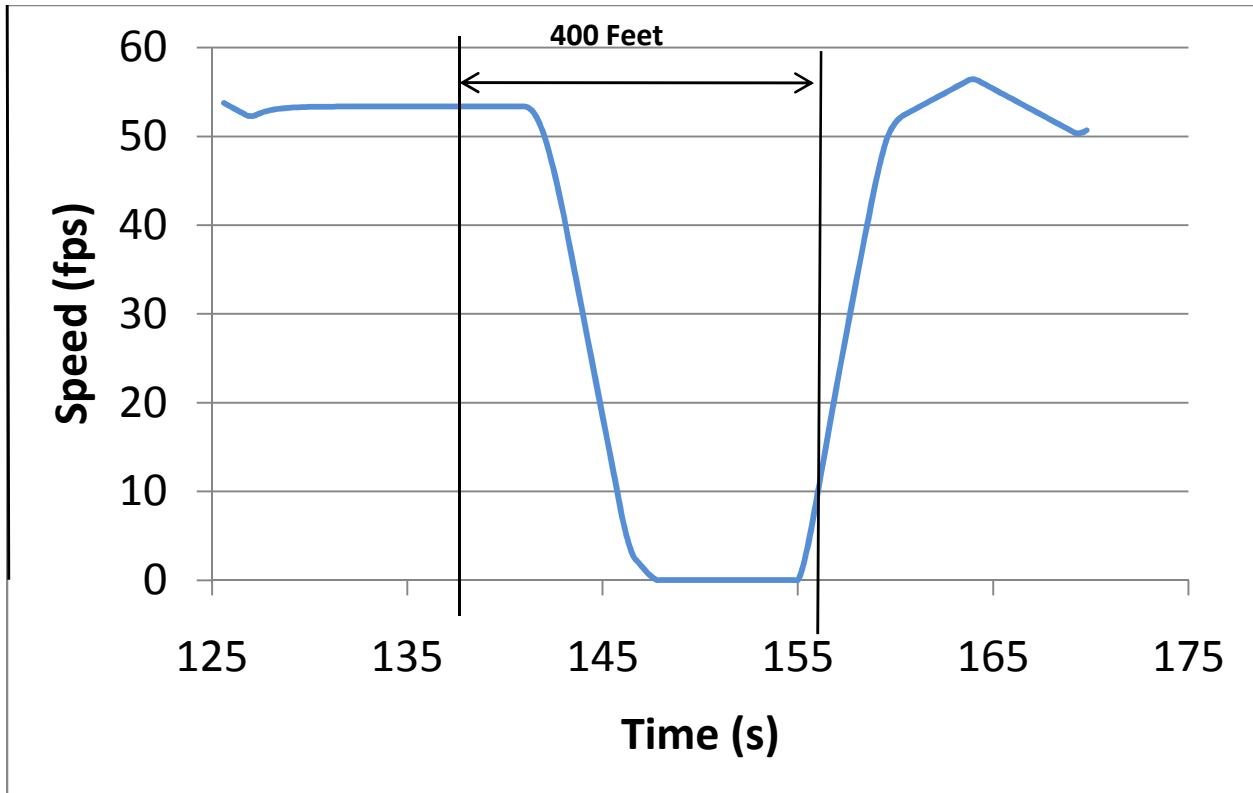
A lot of research has been done on the collection methods of the IntelliDrive data and the use of that data for safety applications. One of the major researches of IntelliDrive data is for the collision avoidance system (19). The signal control is an area which is still under-developed in the IntelliDrive world. Now, with the clear knowledge of all the data that can be obtained with the use of this technology (8), (9), it is possible to implement it in the traffic signal controls. The study presented here aims at bridging the gap between the traditional traffic responsive methodologies with the use of the upcoming IntelliDrive technology. This study provides a methodology that makes use of delay and number of stops data to implement the traffic responsive plan selection.

4.2 IntelliDrive Traffic Responsive System

For the evaluation of Intelli-TRPS, the main weighting parameters that are proposed are the performance factors delay and the number of stops of the system. With the use of IntelliDrive technology, the delay and stops can be obtained on the field. The proposed system makes use of the data that is available in the field as the weights to determining the selection of the timing plan without any assumptions. The following ways are used to determine the delay and the number of stops.

Delay (T)

The actual arrival time of a vehicle to the intersection can be calculated as the difference between the ideal arrival time calculated with the speed measured at 400 feet from the intersection (assuming there is no control effect at that distance) and the actual arrival time of the vehicle. The delay for all the vehicles present within the 400 ft distance of the intersection for each movement is summed up to calculate the total delay for the movement.



Actual Travel Time = 380.91 – 343.21 = 37.21 s
Estimated Travel Time based on speed

$$= \frac{400}{\text{Speed at 400 ft from intersection (in fps)}}$$

$$= \frac{400}{34.112}$$

$$= 11.72 \text{ s}$$

Delay = *Actual Travel Time* – *Estimated Travel Time*

$$= 37.21 - 11.72$$

$$= 25.55 \text{ s}$$

Figure 4-2 Calculation of Delay

Number of stops (S)

IntelliDrive enabled probe vehicles generate start and stop snapshots based on SAE J2735 standards. These standards are based on the current vehicle speed and duration of slow speed travel by vehicles. A stop snapshot is generated when a vehicle registers a current speed of 0 mph for consecutive seconds exceeding the stop threshold (default = 5 seconds). After a stop snapshot is created, a start snapshot will be generated if the current vehicle speed exceeds a start threshold (default = 10 mph). Multiple stop snapshots might be generated when there is an extended stop of 30 or more seconds. To avoid this, the rate of production of stop snapshots is limited by a stop lag parameter (default = 15 seconds), which is the minimum time between stop snapshots with no intervening start snapshot (11), (12), (13).

When IntelliDrive snapshot is generated, it is stored in-vehicle (on the IntelliDrive on-board equipment, or OBE) until it is either transmitted to an RSE encountered later or deleted because of finite storage capacity in the OBE for snapshot data. When an IntelliDrive-enabled probe vehicle is within range of an RSE, it transmits all of the snapshots stored on the OBE. Transmission occurs instantaneously at the transmit range of 400 feet or closer to the RSE, regardless of the number of vehicles transmitting probe data at that moment. The information from each of the vehicle is sent to the RSE where it is aggregated for all the vehicles on each of the movements in that intersection (13), (14), (15).

Formulation

The formulation used to calculate the F parameter in the Intelli-TRPS methodology to determine which timing plan is to be selected is shown below:

$$F_j = \sum_t \sum_i |[\beta_t(S_{it} + \alpha T_{it}) * (V_i - V_{ij})]| \quad (2)$$

Where,

- F_j = sum over all movements (i) of the absolute value of the weighted difference between actual field data and the pre-programmed stops and delay accompanied with each plan.
- S_{it} = the calculated number of stops for movement i per vehicle over time t
- T_{it} = the calculated delay for movement i per vehicle over time t
- α = a user defined constant between 0 and 100 to have the stops and wait time in the same units
- β_t = a factor to average the weights over time t
- V_i = the total volume for the movement i
- V_{ij} = the volume associated with plan j and movement i

The above formula would provide the distance between the existing traffic state and the traffic state that corresponds to the stored timing plans. The minimum distance F_j is selected and the corresponding timing plan is implemented. This is done by finding the distance between the stored traffic states and the existing traffic states. The timing plan corresponding to the minimum F value i.e. the minimum distance would be the selected timing plan for the current traffic state. The formula takes into account the stops, delay and the volume of the current traffic state on the field and the stops, delay and the volume of the traffic states stored in the controller.

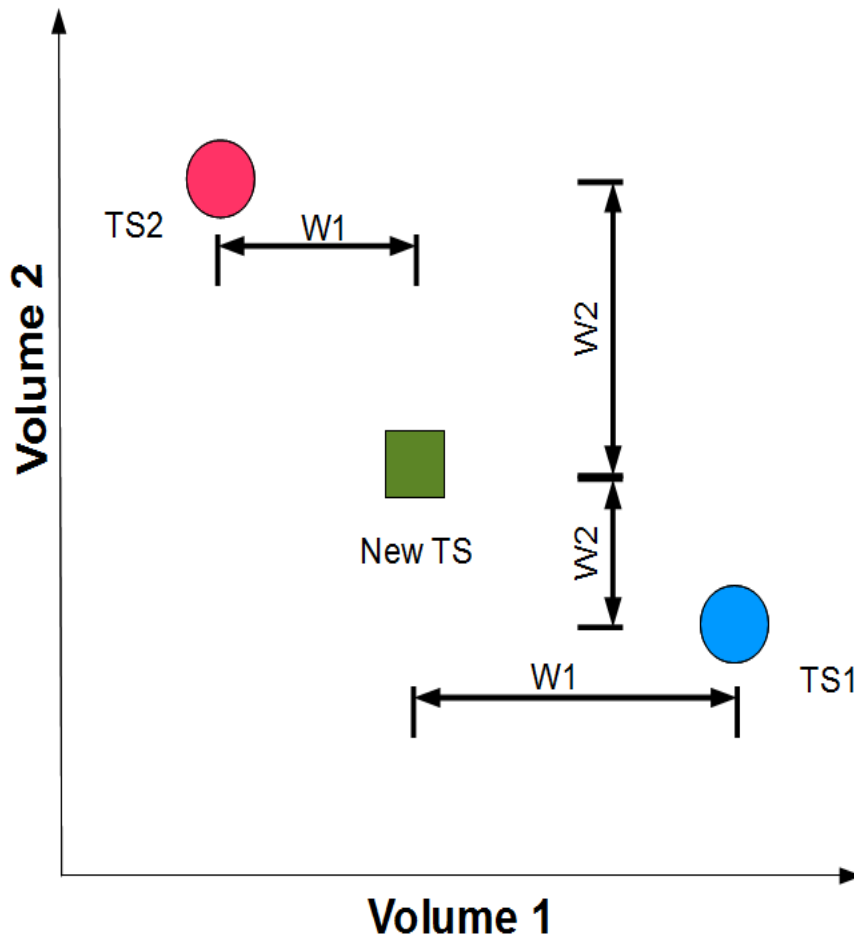


Figure 4-3 State Recognition

The two circles represent the two traffic states, traffic state 1 (TS1) and traffic state 2 (TS2) stored in the controller corresponding to the two different timing plans, timing plan 1 (TP1), and timing plan 2 (TP2) respectively. The volumes for the two movements are shown in the X and Y axes. The square represents the current traffic state for which the corresponding timing plan is to be determined. This is done by multiplying the difference between the volumes of the new and the stored timing plans by $W1$ for movement 1 and by $W2$ for movement 2. $W1$ and $W2$ here represent the weights that are obtained on the field using IntelliDrive, i.e. the sum of the delay and stops for movements 1 and 2. This state recognition can be extended to as many dimensions as there are critical movements.

4.3 Network used for testing

The network that is used for this test is a part of the USDOT IntelliDrive test bed near Detroit, Michigan. A 2-mile arterial with four signalized intersection was used for the test. There are four RSE in the range of this arterial. The IntelliDrive data provided by the Noblis group on their data capture website was used.

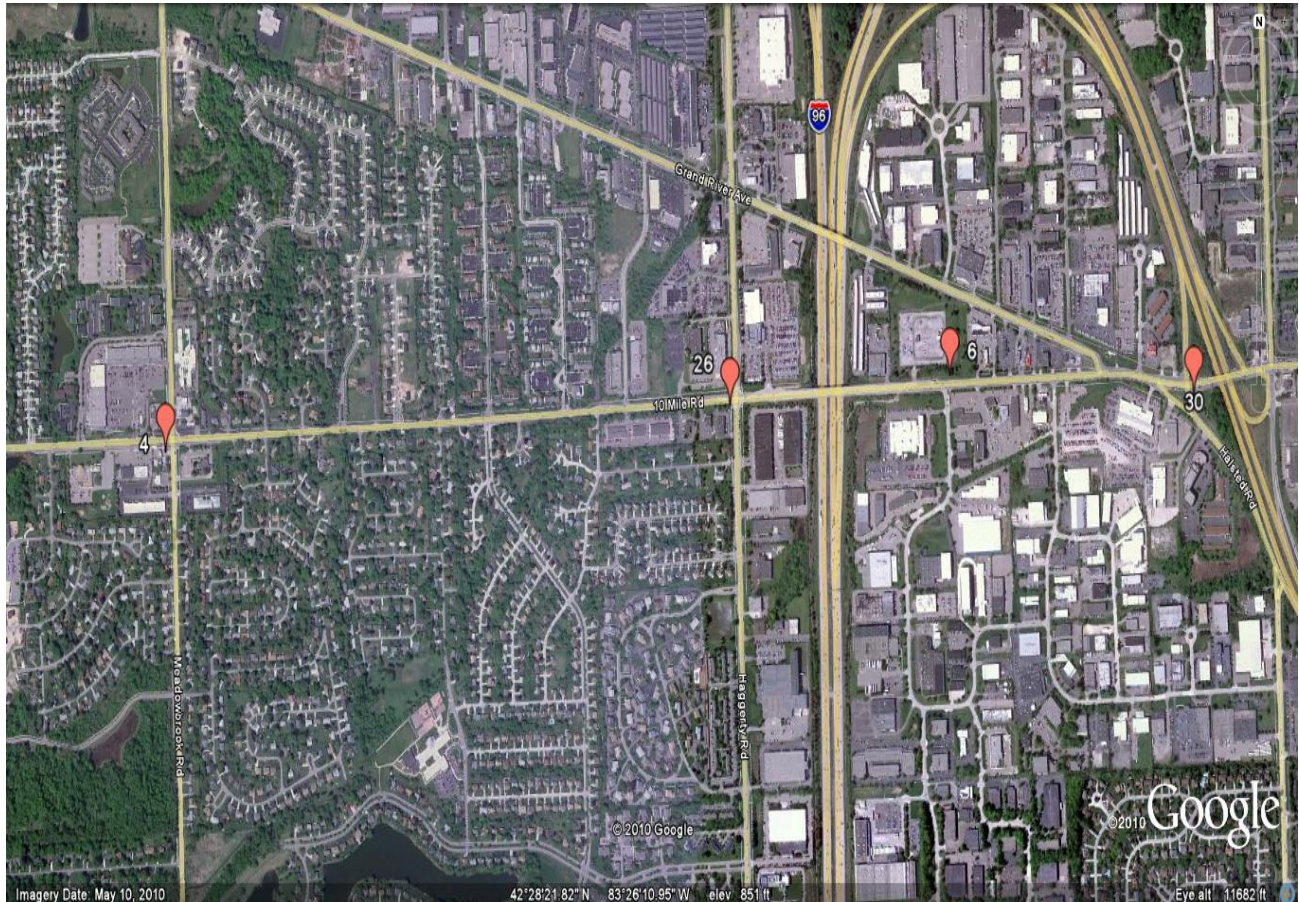


Figure 4-4 Michigan Test Network

Two sets of timing plans were used in the study. The first set was the timing plan data provided by the Road Commission of Oakland County (RCOC). There are three sets of timing plan provided by the RCOC, which were run with all the IntelliDrive data to determine which timing plan would work best with which traffic state. The timing plan and traffic state combination providing the minimum delay were chosen as the traffic state to be stored in the controller. The second set of timing plan was obtained using PASSER (16). The obtained timing plan have a cycle length of 100s, 45s and 45s. This set of timing plans was the one that was optimized for the data that is used in this testing. The test network was modeled in VISSIM and the data used was for a typical weekday from 6AM to 11AM. This created a total of 20 traffic states, one for each 15min interval

The critical movements for the given data were determined with the help of the OD data and correlation analysis. The distribution of the volumes over the 11 movements corresponding

to each of the traffic state is shown in Table 4-1. The volume data for the five traffic scenarios was fed into the VISSIM simulation package. Each scenario was simulated with each of the 6 (3 provided by RCOC and 3 obtained through PASSER) timing plans and the results were recorded. The data collection points were set to collect all the vehicle information. The vehicle information was extracted out of VISSIM and the delay and stops were calculated in a manner described above. The values of the delays and the number of stops for the optimized timing plans are shown if Table 4-2 and 4-3 respectively. The Intelli-TRPS methodology was used to calculate the F value for each of the traffic states. The minimum value of F_j was considered and the timing plan corresponding to the minimum F_j value was the timing plan selected to be implemented. This was done for both the set of timing plans.

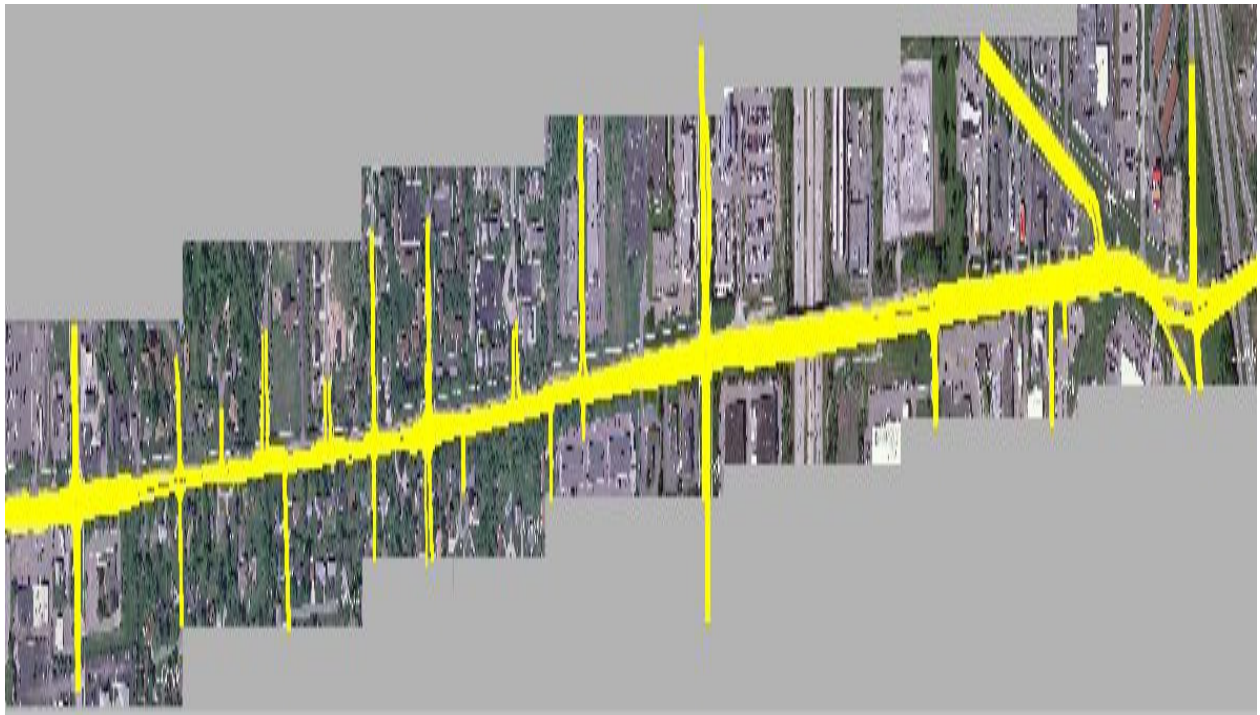


Figure 4-5 Network modeled in VISSIM

Traffic State/Detector	1	2	3	4	5	6	7	8	9	10	11
1	39	0	36	0	3	0	0	18	3	24	36
2	46	0	53	0	0	0	0	30	6	28	34
3	71	0	53	0	0	0	0	34	10	26	40
4	72	0	65	0	0	0	0	49	12	38	55
5	95	23	22	41	9	13	43	42	16	9	55
6	44	34	21	35	7	25	50	1	24	0	90
7	42	48	9	48	6	27	48	3	18	0	55
8	59	55	12	52	8	32	49	2	21	0	89
9	9	50	18	35	7	19	24	2	24	13	81
10	9	50	18	35	7	19	24	2	24	13	81
11	12	0	17	10	17	17	30	3	15	12	54
12	17	47	18	38	1	0	36	3	16	15	60
13	17	1	6	1	32	10	35	24	10	14	52
14	25	0	3	0	36	4	28	28	10	13	42
15	24	0	2	0	34	0	36	30	6	13	53
16	24	1	3	0	38	2	29	35	8	8	59
17	10	1	1	0	38	1	28	14	1	2	10
18	5	2	0	0	21	0	35	0	0	2	4
19	1	1	0	0	22	0	13	1	0	1	2
20	0	0	0	0	17	0	13	0	0	0	1

Table 4-1 Volumes corresponding to the different traffic states

	Detector										
Traffic State	1	2	3	4	5	6	7	8	9	10	11
1	2.81	0.00	2.61	0.00	0.00	0.00	0.00	3.27	0.03	8.73	3.42
2	2.16	0.00	5.12	0.00	0.00	0.00	0.00	4.53	0.89	6.74	2.16
3	4.93	0.00	6.39	0.00	0.00	0.00	0.00	3.98	1.32	5.83	3.33
4	6.21	0.00	6.24	0.00	0.00	0.00	0.00	5.12	2.45	5.94	6.80
5	6.85	1.45	3.98	4.63	0.43	8.26	8.54	6.84	3.29	0.00	5.92
6	5.12	2.61	3.51	5.54	1.63	3.62	6.73	0.43	3.89	0.00	11.04
7	3.05	5.54	0.55	6.25	0.85	4.28	5.73	0.86	4.56	0.00	6.39
8	5.27	6.24	3.45	7.80	2.61	3.68	9.06	0.13	3.76	0.00	10.89
9	0.55	6.39	1.83	8.06	1.83	2.43	3.64	0.01	4.54	0.78	9.23
10	0.01	5.54	2.52	4.93	1.45	4.63	3.86	0.02	5.02	0.89	7.38
11	0.01	0.00	1.04	2.52	1.88	3.07	4.11	0.02	3.18	1.10	6.59
12	0.03	6.75	2.78	1.84	0.00	0.00	5.02	0.01	2.78	1.00	12.68
13	2.61	0.02	0.43	0.00	5.12	1.87	6.84	3.42	2.95	0.96	6.24
14	2.03	0.00	0.86	0.00	4.29	0.00	7.35	4.56	0.14	0.83	5.93
15	4.55	0.00	0.12	0.00	6.25	0.00	3.45	8.12	0.02	1.34	7.10
16	2.78	0.02	0.13	0.00	6.72	0.00	1.67	2.46	0.52	2.18	5.03
17	1.04	0.01	0.52	0.00	3.98	0.00	4.88	2.89	0.00	0.00	2.08
18	0.55	0.12	0.00	0.00	1.04	0.00	6.12	0.00	0.00	0.03	0.82
19	0.35	0.02	0.00	0.00	3.74	0.00	1.98	0.00	0.00	0.02	1.84
20	0.00	0.00	0.00	0.00	3.74	0.00	2.81	0.00	0.00	0.00	0.83

Table 4-2 Delay (T) for different timing plans corresponding to the different movements for optimized timing plan

Traffic State	Detector										
	1	2	3	4	5	6	7	8	9	10	11
1	1	0	2	0	2	0	0	1	0	3	2
2	1	0	3	0	0	0	0	1	0	2	1
3	2	0	3	0	0	0	0	0	1	2	1
4	2	0	2	0	0	0	0	0	1	3	1
5	3	1	1	4	0	3	4	5	1	0	3
6	2	1	1	3	1	1	2	0	1	0	5
7	4	2	0	3	0	2	3	0	1	0	3
8	1	3	2	5	0	3	4	0	1	0	5
9	0	3	1	4	2	2	1	0	1	0	3
10	0	2	2	2	1	1	1	0	1	0	1
11	0	0	1	2	1	4	2	0	1	1	2
12	0	2	2	0	0	0	3	0	1	1	4
13	1	0	0	0	2	1	1	2	1	1	2
14	2	0	0	0	2	0	1	3	0	0	3
15	2	0	0	0	1	0	1	4	0	1	4
16	2	0	0	0	2	0	1	1	0	1	3
17	1	0	1	0	1	0	2	1	0	0	2
18	0	0	0	0	1	0	4	0	0	0	0
19	0	0	0	0	1	0	2	0	0	0	1
20	0	0	0	0	3	0	2	0	0	0	0

Table 4-3 Number of Stops (S) for different timing plans corresponding to the different movements for optimized timing plan

To ensure that the developed system is robust, there were various combinations of delay and stops prevailing on the field were considered. In the first method the values of stops and delay, i.e. the weights, were considered for each of the states individually. For example, for traffic state 4, the delays and stops corresponding to traffic state 4 were considered. The second method, the weights were averaged for the last two states including the prevailing states. For example, for traffic state 4, the stops and delay were averaged for traffic state 3 and 4. Then the weights were average over the last three states which mean that for finding the delay for traffic state 4, the weights were averaged over states 2, 3 and 4. For the final test, the stops and delay were averaged over the previous 4 states. Averaging the weights over the last two, three or four states, would lead in a system that would not be as optimal as when considering the individual weights. It was observed that even when using the weights corresponding to each traffic state individually, the system was robust and did not fluctuate between different timing plans, thus the weights were considered individually and not averaged over the previous states. There is a graph which shows how the system behaves with the different considerations of weights.

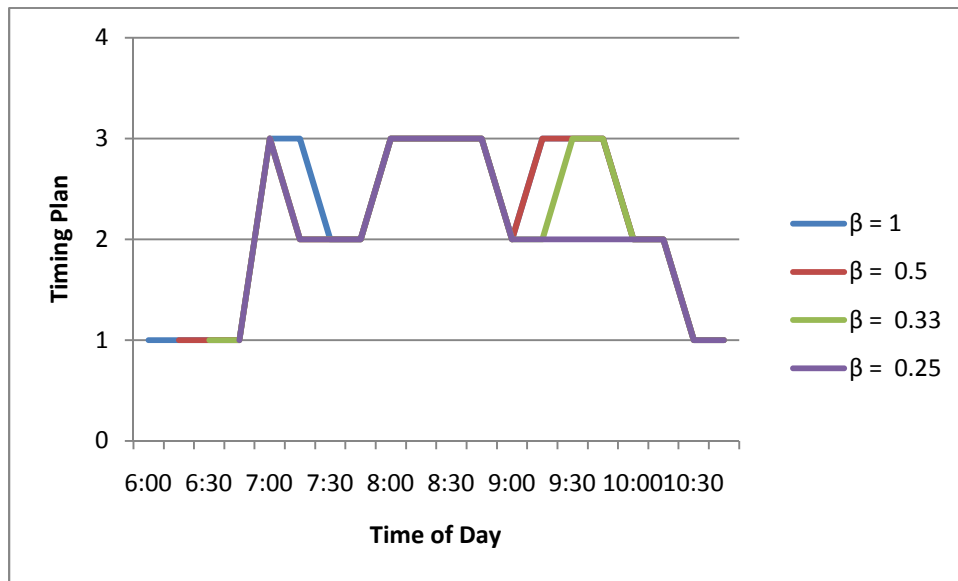


Figure 4-6 Timing Plan selection with different values of β

4.4 Traditional Traffic Responsive System

In order to compare the proposed system with the existing system, the same traffic data was used and the timing plans were selected based on the traditional pattern matching TRPS method.

The detector count and occupancy data were obtained from VISSIM for 20 traffic scenarios to conduct the pattern matching method. Different weights were assigned to the eight system detectors movements in our case). The weights were optimized by using the solver tool in Excel. They are shown in Table 4-4 and 4-5. The K factor used in our case is 50%. The F_j was calculated using equation 1 and the minimum F_j was matched with the corresponding timing plans. Table 4-7 shows the actual delay for that state obtained by the timing plan selected by traditional TRPS mechanism, the delay obtained by the timing plan selected using the IntelliDrive based TRPS and the percentage improvement in delay obtained when using the

IntelliDrive based TRPS mechanism for the prevailing traffic states when using the RCOC timing plans. From the table we can see that using the IntelliDrive based data would result in a decrease in the overall system delay by 13% when compared to the traditional TRPS system with optimized weights. Table 4-8 shows the actual delay for that state obtained by the timing plan selected by traditional TRPS mechanism, the delay obtained by the timing plan selected using the IntelliDrive based TRPS and the percentage improvement in delay obtained when using the IntelliDrive based TRPS mechanism for the prevailing traffic states when using the optimized timing plans. The error in the results when using the traditional TRPS mechanism can be attributed to the detector weights. As mentioned above, there is no fixed rule that is used to determine the weights given to the detectors. The weights are provided at the discretion of the traffic engineer and there might be cases where the weights are wrongly assigned which would lead to the improper functioning of the system.

Detector	1	2	3	4	5	6	7	8	9	10	11
Weights	3	6	2	3	5	6	4	8	9	6	3

Table 4-4 Weights for traditional TRPS for original timing plan

Detectors	1	2	3	4	5	6	7	8	9	10	11
Weights	3	5	4	6	7	8	6	10	9	7	9

Table 4-5 Weights for traditional TRPS for optimized timing plan

Traffic State	Delay		Percent Improvement
	IntelliDrive	Traditional	
1	3.68	3.68	0.00
2	4.98	6.98	28.63
3	3.28	3.98	17.59
4	2.69	2.69	0.00
5	4.50	4.50	0.00
6	10.01	11.25	11.02
7	11.28	12.98	13.12
8	11.96	12.11	1.23
9	6.59	7.37	10.50
10	11.38	11.97	4.90
11	12.43	13.02	4.53
12	11.36	12.54	9.41
13	12.76	12.76	0.00
14	10.36	10.98	5.66
15	10.10	11.01	8.24
16	9.87	9.87	0.00
17	7.81	8.79	11.15
18	4.28	4.28	0.00
19	4.38	4.38	0.00
20	2.35	2.35	0.00
		TOTAL	6.30

Table 4-6 Percentage Improvement over Traditional TRPS Method for optimized timing plan

When the prevailing traffic states on the field and the stored traffic state in the controller differ, the selection of the traffic state relies heavily on the weights that are assigned to the detectors. As there are no set rules for the determination of the weights and they are solely based on the experience and the observation of the traffic engineer, there are chances that the weights assigned are incorrect. This would lead to the selection of erroneous timing plan which would in turn result in the increase in delay of the system. The availability of the IntelliDrive data provides us the ability to utilize the performance measures as the input data for the calculation of optimized timing plan. With the use of delay and stops as the input data, it is possible to select a timing plan which would minimize the input, i.e. the delay and the number of stops in the system. The aim of optimizing any traffic signal is to improve the system by minimizing the total delay and the number of stops. The results here show that the use of the IntelliDrive based data can lead to a decrease in the total system delay by 6.3% when using the optimized timing plans.

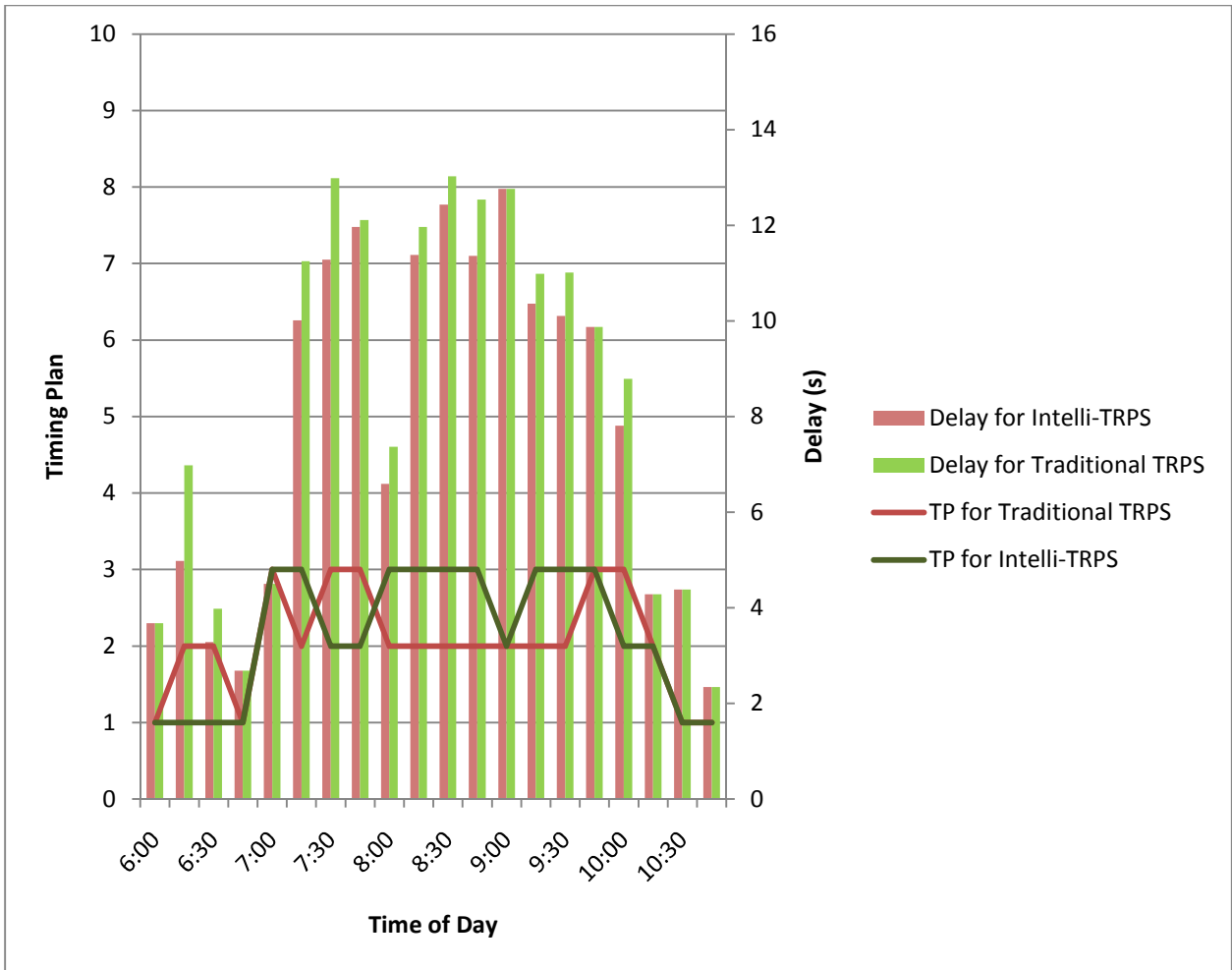


Figure 4-6 Timing Plan selection for optimized timing plan

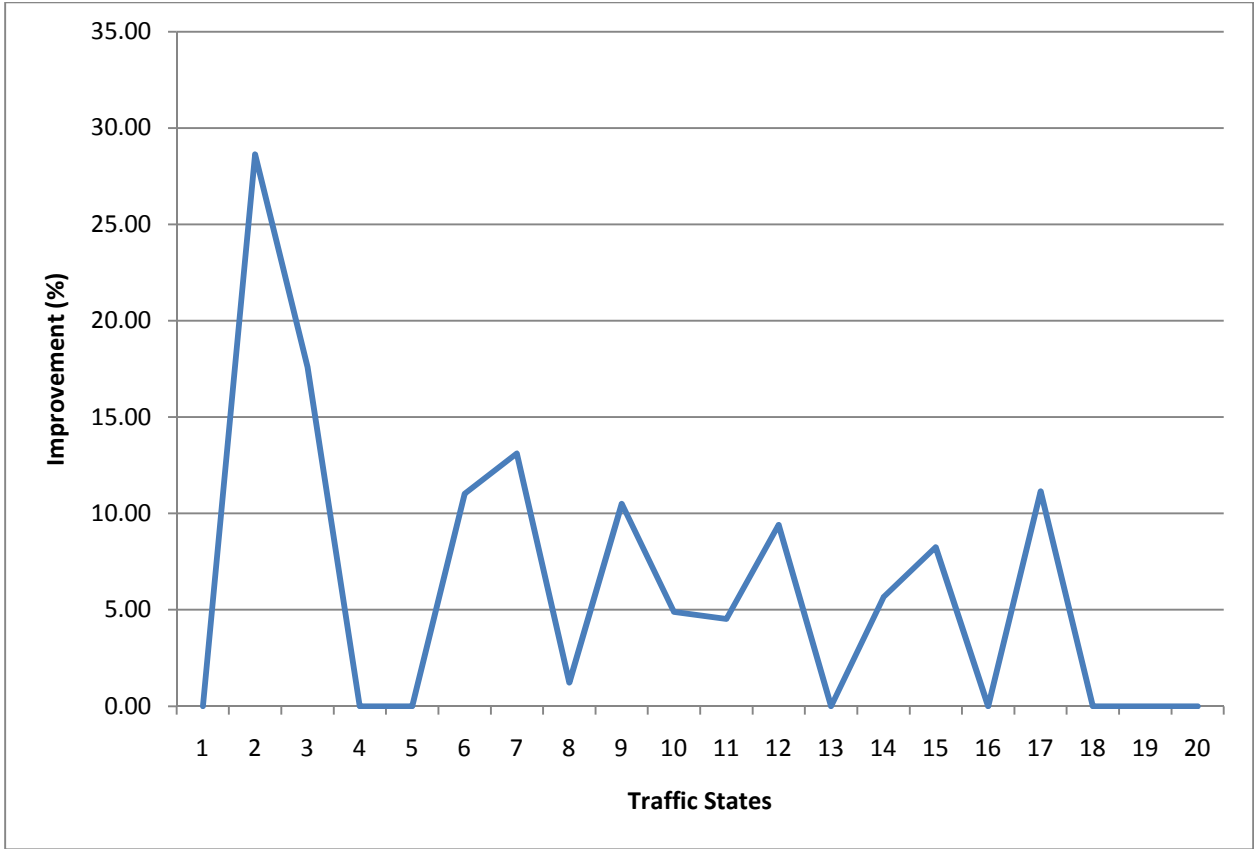


Figure 4-7 Percentage Improvement over traditional TRPS Method (using optimized timing plans)

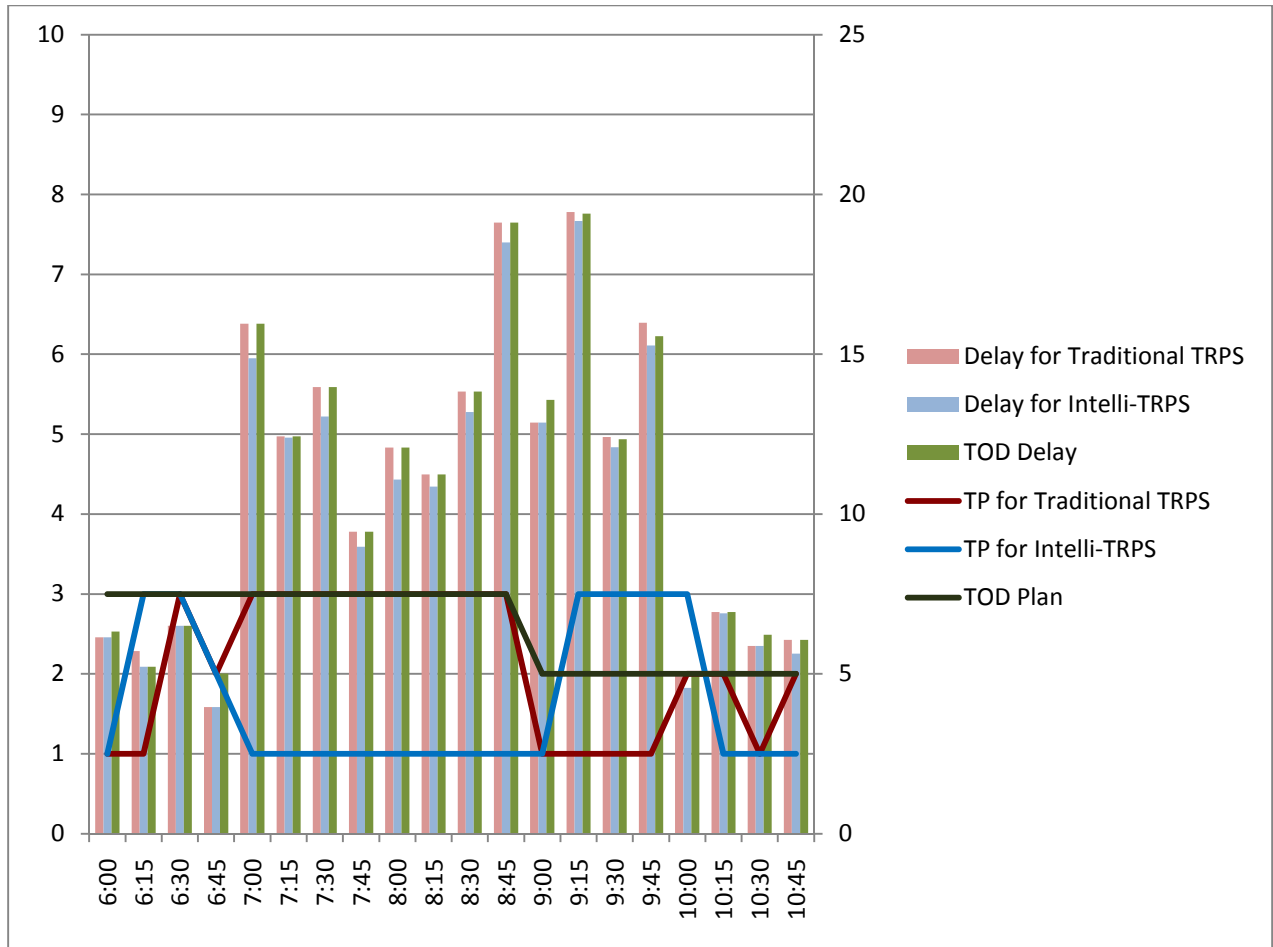


Figure 4-8 Timing Plan selection for original timing plan

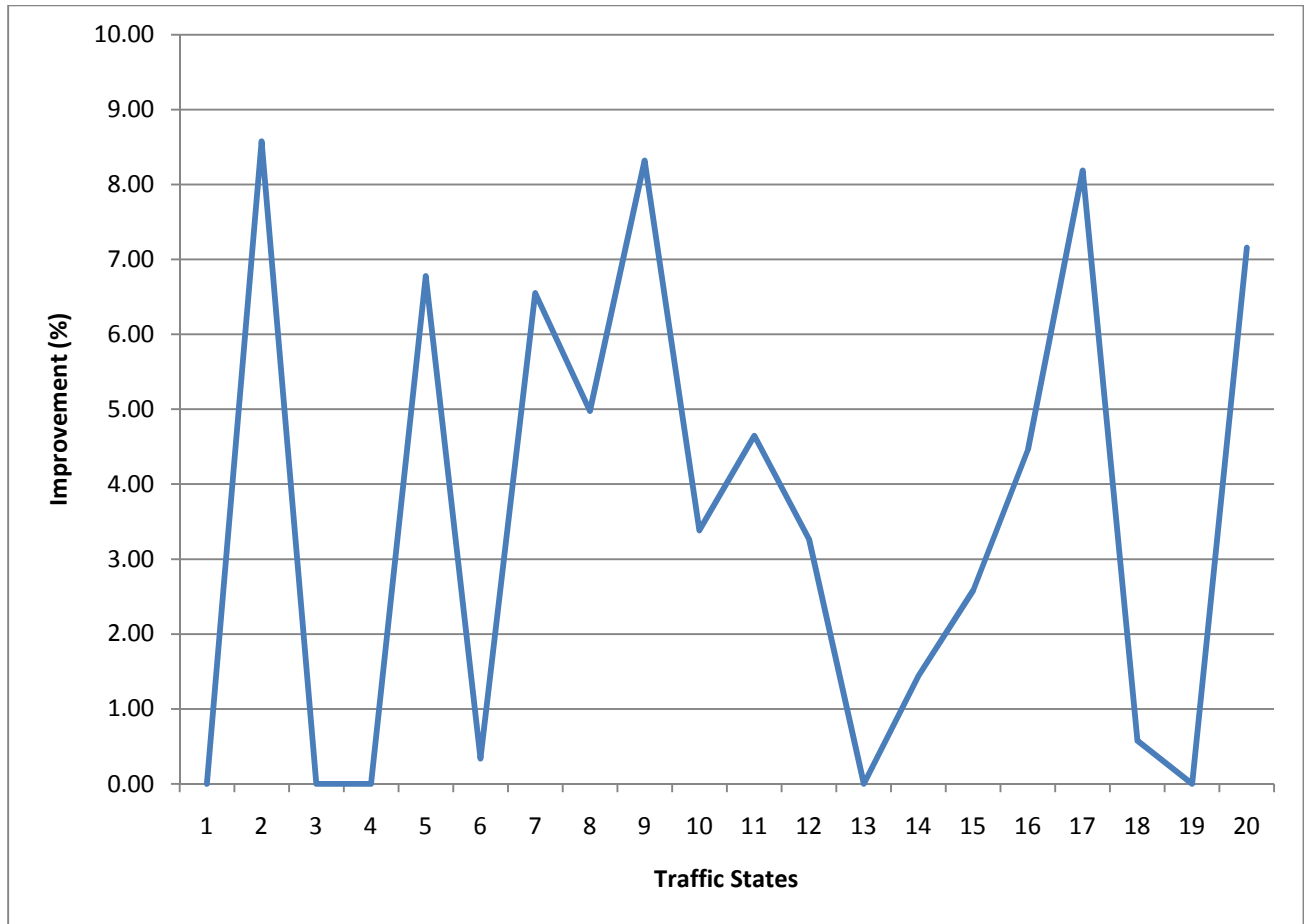


Figure 4-9 Percentage Improvement over traditional TRPS Method (using original timing plans)

4.5 Analysis of Results

As observed from the results, the Intelli-TRPS works better when compared to the traditional TRPS system. When the prevailing and the stored traffic state differ, the selection of the traffic state relies heavily on the weights that are assigned to the detectors. Weights are the measure used to emphasize on particular movement where the detector is located and give it more importance over the other. The weights used for the traditional TRPS system are fixed and do not change with the prevailing conditions on the field. There would be instances on the field where the delay experienced by a particular movement would be more than the other movements and this would keep changing throughout the day. The fixed weights as in the case of traditional TRPS method would not be able to incorporate these changes in the importance of the movements and would lead to the selection of erroneous timing plan which would in turn result in the increase in delay of the system. The availability of the IntelliDrive data provides us the ability to utilize the performance measures as the input data for the calculation of optimized timing plan. With the use of Intelli-TRPS methodology, the delay and stops are used as weights, which would enable us to incorporate the change in the importance of the movements and select a timing plan which would benefit the movement with the highest delay. The aim of optimizing

any traffic signal is to improve the system by minimizing the total delay and the number of stops. The results here show that the use of the use of Intelli-TRPS can lead to a decrease in the total system delay by 6.3%. Also, the developed system is robust as it does not fluctuate between different traffic plans as we can see from Figure 4-6. The results were also tested for different market share rates. The analysis of result indicates that the system would perform well with a market share of 40%. At 40% market share the system selects the timing plan which provides the minimum delay.

T-test was performed to test the statistical significance of the results. The p-value obtained was 2.8×10^{-4} which is less than 0.05 and thus our results are statistically significant. Also, the Figure 4-11 shows the error bars for the delays obtained using both the methodologies. As the error bars do not overlap when the timing plans selected and hence the delays obtained are different, our results are statistically significant.

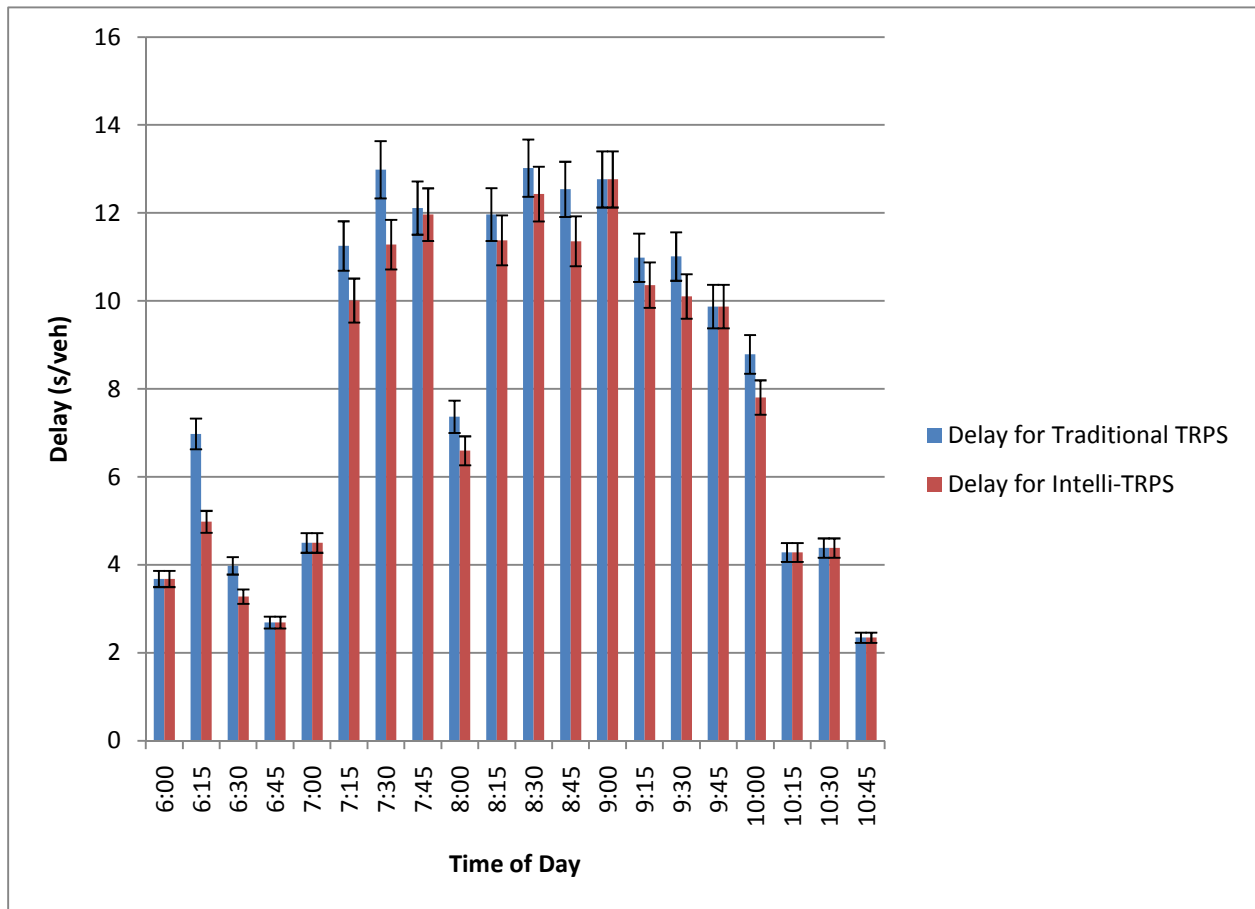


Figure 4-10 Statistical Analysis

4.6 Conclusion

This paper proposes a method that can be used to integrate the current traffic responsive mode of operation with the upcoming IntelliDrive technology. An arterial in the IntelliDrive Michigan test bed was considered for this study and the current TRPS mechanism was compared with the proposed IntelliDrive based traffic responsive mechanism. It was found that the proposed system performed better in selecting the plan which would reduce the system delay. Using the data obtained from IntelliDrive technology, it is possible to compute the total delay and number of stops encountered by each vehicle on the field and thus these parameters can be directly used to compute the best available timing plan for the existing traffic scenario. The study shows that using the IntelliDrive based TRPS results in the selection of the traffic plan reduces the delay of the system by 6.3% compared to the traditional TRPS mechanism. According to the USDOT, if IntelliDrive data improves signal operation by 10%, it would save an estimated 1.7 million hours of delay, 1.1 million gallons of gasoline, and 9,600 tons of CO₂ emissions a year, at full deployment (18).

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5. Summary and Conclusion

5.1 Summary

The IntelliDrive technology has the ability to provide data that would be helpful in enhancement of the existing traffic management applications. IntelliDrive data has attributes that cannot be measured using traditional surveillance technology and which can be used for the development of new traffic management and traveler information applications. The traffic responsive plan selection (TRPS) mode of operation is used in coordinated traffic network to improve the performance of the system. This mode of operation has the ability to implement the best possible timing plan for the existing traffic conditions by switching between timing plans. The data from IntelliDrive technology can be utilized in the traffic responsive mode to improve the system performance by reducing the overall delay in the system. This paper proposes a system that can be used to integrate the data obtained from the IntelliDrive technology to the traffic responsive mode of operation. The proposed method, Virginia Tech Intelli-TRPS, utilizes the number of stops and delay of the vehicles in an intersection as a basis for the implementation of the best timing plan for the prevailing traffic condition. The study shows that using the IntelliDrive based TRPS results in the selection of the traffic plan that minimizes the delay of the system and thus results in better system performance compared to the traditional traffic responsive mechanism. The weights that are used in the traditional TRPS mechanism are determined empirically by the traffic engineers, which in many cases lead to erroneous results. With the help of IntelliDrive technology, the delay and the number of stops can be obtained on the field, and the system proposes to use these as the weights. The ultimate aim of any methodology is to decrease the overall delay in the system and by using the delay as the weights, we aim to achieve it.

The thesis covers the basic concepts of the Traffic Responsive Methodology and the IntelliDrive technology. It talks about the two different types of TRPS methodology used, i.e. the Pattern Matching and the Threshold Mechanism. Among the two TRPS mechanism, the pattern matching mechanism has a greater potential to differentiate between the timing plans and to implement the timing plan closest to the existing system. The data obtained with use of the IntelliDrive technology is richer in its contents as compared to the traditional passive sources of data. The aim of this thesis is to take advantage of the more robust data and utilize it to enhance the current TRPS technology. There is On-board equipment in the vehicles which collects and stores the data for each of the vehicle. This data is then transmitted to the Roadside equipments with the help of Dedicated Short Range Communication. The RSE then process the data and if required sends it to the Traffic Management Centers for further processing. The TMC then transmits the data to the network and administrative users.

Next, the thesis proposes a methodology, Intelli-TRPS, which would make use of the IntelliDrive data to make improvements in the existing Pattern Matching TRPS Mechanism. The proposed system utilizes the delay and the number of stops obtained from the field as the weights instead of the constant empirical weights used in the traditional method. Five intersections of the Reston Parkway arterial were considered for this study and the current TRPS mechanism was compared with the proposed IntelliDrive based traffic responsive mechanism. The results indicate that the proposed system works much better when compared to the traditional system. The ultimate goal of a traffic signal methodology is to reduce the overall delay in the system and the proposed system is able to achieve that.

In the next chapter the Virginia Tech Intelli-TRPS was tested with actual IntelliDrive data that was obtained from the Noblis group. This data is obtained from the IntelliDrive testbed that is developed in Michigan. One of the arterials was considered for the study. The arterial consisted of 4 RSEs. The Road Commission of Oakland County provided the timing plan used in that arterial. The testbed was simulated in VISSIM and the data obtained was used for the calculations. The delay and the number of stops were calculated and the proposed methodology was implemented. The traditional TRPS mechanism was also tested for comparison. There were two sets of weights used for testing the traditional system. One were non-optimized weights and the other optimized weights. The results indicate that the proposed IntelliDrive TRPS system works better than the traditional TRPS system even when using optimized weights for the traditional system. This improvement can be attributed to the use of weights. In the traditional system the weights are determined empirically but with IntelliDrive, it is possible to obtain the delay and the number of stops in the field and these can be used as a measure to implement the TRPS mechanism.

5.2 Conclusion

This thesis has presented a methodology, Intelli-TRPS, which improves the working of the traffic responsive control strategy with the help of IntelliDrive technology. The main measures of effectiveness of any traffic system are delay and number of stops. The number of stops made by vehicles is an important measure of quality of traffic flow progression. While reducing the number of stops usually leads to a reduction in incurred delay, fewer stops also often lead to reduced fuel consumption and vehicle emission. The delay experienced by drivers while traveling on a section of road is commonly used to assess quality of travel. The quality of services reduces with the increase in delay.

In TRPS mechanism, the weights are assigned to particular movements based on the significance of the movements. The higher the weights the more significant the movement would be. The weights used for the traditional TRPS system are fixed and do not change with the prevailing conditions on the field. There would be instances on the field where the delay experienced by a particular movement would be more than the other movements and this would keep changing throughout the day. The fixed weights as in the case of traditional TRPS method would not be able to incorporate these changes in the importance of the movements and would lead to the selection of erroneous timing plan which would in turn result in the increase in delay of the system.

The availability of the IntelliDrive data provides us the ability to utilize the performance measures as the input data for the calculation of optimized timing plan. IntelliDrive provides a data environment which is richer than the data obtained using the traditional surveillance methods. With IntelliDrive, it is possible to obtain the vehicle status data such as the vehicle speed, acceleration, position, etc. With the use of this data, the traditional methodologies can be improved and be made more optimal.

This thesis proposes a methodology, Intelli-TRPS which incorporates the traditional TRPS methodology with the data obtained from IntelliDrive. With the use of Intelli-TRPS methodology, the delay and stops are used as weights, which would enable us to incorporate the change in the importance of the movements and select a timing plan which would benefit the movement with the highest delay. Importance is given to the movement which experiences the

highest delay and stops which results in self optimization of the system. In the traditional method, the weights are determined off the field and they need to be optimized which is not always done by the traffic engineers. Also, as mentioned earlier, the weights used in the traditional system are fixed and they do not reflect the traffic conditions prevailing on the road. Intelli-TRPS overcomes this drawback of the traditional system and thus results in a system which is self-optimized. The other advantage of the Intelli-TRPS method is that unlike the traditional TRPS system, it includes the performance measures in the calculations for the timing plan to be implemented. Thus, the timing plan selected would aim to reduce the delay and the stops for that movement. So, Intelli-TRPS improves the system by minimizing the delays and the stops.

The evaluation of the Intelli-TRPS indicates that there is a reduction in overall delay of the system when compared to the traditional method even when using the optimized weights in the traditional system. The most important measure of effectiveness of any system is the delay. A reduction in delay would also have an effect on the environment. A benefit cost analysis study by the USDOT suggests that if IntelliDrive data improves signal operation by 10 percent, it would save an estimated 1.7 million hours of delay, 1.1 million gallons of gasoline, and 9,600 tons of CO₂ emissions a year, at full deployment (16). This study concludes that the use of Intelli-TRPS would decrease the delay by 6% as compared to the traditional methods. This methodology is particularly useful because it self-optimizes the weights and eliminates the need to optimize the weights offline as in case of traditional method.

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