IMPLEMENTATION OF INTERSECTION MANAGEMENT ALGORITHM CONSIDERING AUTONOMOUS AND CONNECTED VEHICLES

By

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To my parents
ACKNOWLEDGMENTS

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Abstract of Thesis Presented to the Graduate School of the University of Florida in Partial Fulfillment of the Requirements for the Degree of Master of Science

IMPLEMENTATION OF INTERSECTION MANAGEMENT ALGORITHM CONSIDERING AUTONOMOUS AND CONNECTED VEHICLES

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Autonomous vehicle development is on its peak these days. The thought of having self-driving cars is close to fruition. A lot of work has been done in the last decade in the field of Autonomous Systems.

There are cars that can drive better than humans on highways. They allow for higher speed and safety. But infrastructure does not exist that is friendly to autonomous vehicles such as at intersections. Autonomous vehicles cannot use existing infrastructure to operate efficiently as the current infrastructure has been designed keeping human driven vehicles in mind. New algorithms need to be developed which will allow autonomous vehicles to use existing infrastructure without entirely changing the infrastructure. In this way both human driven and autonomous vehicles can use the infrastructure and human driven vehicles can also take advantage of developments done in the autonomous vehicle field. This can be achieved using smarter intersections which can communicate with the vehicles using vehicle-to-vehicle (V2V) communication and can use the data from the vehicles to optimize signal phase and timing. Additionally
such an intersection can also control the flow of traffic by controlling the speed of vehicles.
CHAPTER 1
BACKGROUND

Autonomous Vehicles

Autonomous vehicle development is at its peak right now and has reached a level where one can imagine them running on every street and city in a few years. This system allows for complete control over the vehicle and has the potential to revolutionize the highway system. They allow higher yet safer speeds and have the potential to remove traffic congestions.

An autonomous vehicle is a vehicle that is controlled by an onboard computer and gets its input from sensors like GPS, LIDAR, Computer Vision and stored terrain information. The onboard controller processes all the information in real-time and manipulates vehicle controls to keep the vehicle on its path.

Extensive research has been done on how these vehicles will drive on open roads and in congested traffic. How these vehicles will deal with intersections or with human driven vehicles has not been dealt with in details.

A number of algorithms have been developed for navigation of autonomous vehicles through intersections but most are focused on 100% autonomous vehicle use. The benefits provided by these algorithms reduce significantly when human driven vehicles are introduced side by side with autonomous vehicles.

The focus of this work is to develop a system that will allow an optimal co-existence of human driven and autonomous vehicles. Various approaches are investigated to find out which one is the most optimal and will allow autonomous vehicles to use the existing infrastructure without many changes or modifications.
Navigation

The current infrastructure is based on human driven vehicles and is not friendly with Autonomous vehicles. Existing systems require that the driver is alert of the other cars and their intentions before making a move. Every intersection is different from every other in regard to placement of lights and signage.

Existing Infrastructure

Currently the most used traffic control devices are Stop Signs, Traffic Lights and Yield Signs as shown in Figures 1-1 through 1-3.

Figure 1-1. Sample STOP Sign B2a

A stop sign is a traffic sign to notify drivers that they must stop before proceeding. In the United States, sign B2a is used which is a red octagon with STOP written in bold letters. This traffic sign requires that the driver stops before crossing the Stop Line and yields to other traffic (in case other traffic does not stop) or follows a First
in First Out rule to move ahead. It also requires that the driver yields to the car on his right in case both vehicles arrived at the same time. In US the stop sign is used in places where the installation of traffic light is not justified due to cost and low traffic flow.

Figure 1-2. Sample Yield Sign

In certain places such as an intersection with pass/right turn lanes the Yield sign is used. It requires the driver to slow down and stop / give way to the approaching traffic else the driver can continue on his path. According to the Manual on Uniform Traffic Control Devices [1] a yield sign is used in cases when

- Approaches to a through street or highway does not require a mandatory stop.
- Channelized turn lane that is separated from the adjacent travel lanes by an island, even if the adjacent lanes at the intersection are controlled by a highway traffic control signal or by a stop sign.
- Travel lanes merge and control is needed as road geometry may limit sight
Figure 1-3. Traffic Lights (Vertical Orientation)

The most popular of the traffic signals/devices is the traffic light as shown in Figures 1-3 and 1-5. This device alternates the right of way by showing signals to traffic (red for stop and green to go with yellow to warn about an upcoming signal change. These devices either work on preset timings or use an in road loop sensor to sense the presence of vehicles (Figure 1-4).

They may be installed in Horizontal or Vertical Orientation above the intersection and in some cases some additional signals are installed some distance before the actual intersection if the intersection cannot be seen from a distance.

Every intersection is unique when it comes to its design and placement of devices, and this leads to the next section about the need for newer systems.
Need for Newer Infrastructure

Every traffic control device present today has been designed keeping human drivers in mind and some devices require that the driver uses his own discretion when navigating through it.
The driver needs to know the order in which the cars arrived at a STOP sign so they can determine when it is their turn to proceed. Making a right turn at a traffic signal requires that the driver check for incoming traffic before merging.

An autonomous vehicle cannot easily perform these tasks without communicating with the intersection or other cars and this requires changes to existing infrastructure.

It is also important to make sure that the changes do not render the intersections unusable for human driven vehicles.

**Literature Review**

Algorithms have been developed by various universities which will allow the autonomous vehicle to navigate through an intersection and they have been proved to be more efficient than traditional traffic light. However these algorithms rely on several assumptions and require changes to the existing system that renders them inefficient to use with human driven vehicles. Some of the algorithms are reviewed here such as the FCFS Algorithm by the University of Texas- Austin and a similar algorithm by Ismail Zohdy of Virginia Tech

**Existing Algorithms**

The Autonomous Intersection Management Algorithm developed by Peter and Stone of University of Texas – Austin is presented first.

The algorithm developed by Dr. Dresner and Dr. Stone is titled Multi-agent Traffic Management. In the first policy called FCFS (First Come First Serve) they assume all vehicles are autonomous and the vehicle follows an exact given path by the algorithm. Each and every intersection is divided into an $n \times n$ grid where $n$ is the granularity of the intersection. The algorithm works on the basis of reservation. Each vehicle approaching
an intersection sends in a request to the intersection manager. The reservation includes the following information [2].

- The time the vehicle will arrive
- The velocity at which the vehicle will arrive
- The direction the vehicle will be facing when it arrives
- The vehicle’s maximum velocity
- The vehicle’s maximum and minimum acceleration
- The vehicle’s length and width

From this information the intersection computer simulates the path of the vehicle and notes the cells of the grid used by the vehicle. This process is repeated for every vehicle and if any of the cells required by the vehicle are not available then the request is denied. Otherwise the system accepts the request (Figure 1-6).

![Figure 1-6. Successful Vs. Failed Reservation under AIM](image)

The driver agent behaves according to the information/ parameters given by the intersection manager. If the request is approved the driver agent continues proceeding
towards the intersection. However, if the request is denied it slows down and send the request again after a fixed time. If the driver agent determines that it cannot keep the reservation it cancels the existing reservation and the reservation making process begins again.

The algorithm was not implemented in a real world scenario but they used a simulation to determine efficiency of the system [2].

The other systems they discussed are called FCFS-LIGHT and FCFS-EMERG. When human driven vehicles are also present at the intersection, the FCFS-LIGHT is preferred. This policy is designed to accommodate both human drivers and autonomous vehicles. Under this policy, if the light is green the policy ensures that it is safe for the vehicles to drive through the lane that is regulated by the light and also to grant reservations to autonomous vehicles in other lanes where human driven vehicles are not present, similar to a right on red.

Under this policy the intersection is divided into an $n \times n$ grid similar to the policy described earlier and the same parameters are sent to the intersection manager by the driver agent. The lane which is given the green light is considered off limits and no reservation is made which intends to use the light controlled lane. This allows vehicles in other lanes to continue moving w/o affecting the light controlled lane [3]. (Figure 1-7).
Figure 1-7. Every lane is given green light in a cycle for human driven

This policy subsumes the FCFS policy. FCFS is just like a special case of FCFS-LIGHT. The other policy explained is FCFS-EMERG. This policy is used when an Emergency Vehicle wants to pass through an intersection and is used to give priority to the Emergency vehicle. Under this policy all other reservation except for the lane in which the emergency vehicle is travelling is denied and the lane containing the Emergency Vehicle is given an unconditional Green Equivalent until the Emergency vehicle has crossed the intersection. As soon as the Emergency vehicle clears the intersection the policy switches back to FCFS or FCFS-LIGHT based on traffic composition.
The algorithm entitled “Optimizing Driverless Vehicles at Intersections” by Ismail Zohdy and Hesham Rakha of Virginia Tech Transportation Institute is now described.

This algorithm is a heuristic optimization algorithm for controlling driverless vehicles at unsignalised intersections. Similar to the algorithm discussed before, they have driver agents and an intersection manager called autonomous agents and manager agent. The manager agent has full authority over the autonomous agent. This allows the manager to overcome any selfish behavior by an autonomous vehicle [3].

The autonomous agent provides the intersection manager with the following information.

- Initial Speed, location and acceleration
- Vehicle Characteristics (Power of engine, Weight of Vehicle, etc.)

Apart from this information, it also considers the weather station measurements and surface condition sensing along with intersection characteristics.

According to Zohdy & Rakha previous research in this area had assumptions and did not capture various aspects of driverless vehicles. For example

- All current simulators do not optimize the movements of driverless vehicles for the global benefit (total delay minimization) at intersections.
- All current simulators do not account for weather condition impacts
- Most of the simulators do not use the vehicle physical characteristics (e.g. vehicle power, mass and engine capacity) in the simulation process
- Most of the simulators do not allow the intersection manager to control the movements of driverless vehicles and only grant the permission to pass or not.

To cover for these assumptions Zohdy and Rakha developed a new simulator called OSDI (Optimization Simulator for Driverless vehicles at Intersection). The general concept of OSDI is to determine the optimum location, speed, and acceleration of all
vehicles along with minimizing the time delay. The model used by Zohdy and Rakha also made certain assumptions which will be discussed later.

The process works in 3 steps. First it calculates the Conflict Zone Occupancy Time (CZOT) then adjusts the speed of one vehicle to avoid the conflict and then finalize the decision and send it to the vehicle [4]. (Figure 1-8)

Figure 1-8. Sample Intersection showing Collision Zones

The system initially advises all vehicles to accelerate to the desired speed (i.e. max safe speed) and if a conflict is detected it reduces the speed of one vehicle while maintaining the other to go at the desired speed. A sample time diagram is shown in Figure 1-9.
This adjustment is done for every vehicle and the process is repeated after a small time to adjust for any unforeseen circumstance/issue. Zohdy and Rakha compared this system to an All Way Stop Control and ran up to 1000 simulation and compared the results. They found that their system reduced the average wait time by 35 seconds which is approximately a 65% reduction in total intersection delay [4] as shown in Figure 1-10.
Assumptions and Drawbacks in Existing Algorithms

There are certain assumptions in both algorithms that will be discussed in this subsection. The assumptions in AIM are presented first and it will be shown how it affects the implementation and performance in the real world.

The FCFS policy limitations and assumptions are discussed first before moving to other policies. AIM assumes that all vehicles are autonomous; they report time of arrival accurately to the controller and can follow the path perfectly while travelling through the intersection [8].

Autonomous vehicles have developed a lot over the last decade but they are still far from being used in a commercial public setting. Moreover the acceptance of autonomous vehicles in the market is unknown. Traffic composition of 100%
autonomous vehicle is at least 10 years from now. During initial stages, the majority of vehicles will still be human driven and sacrificing efficiency for human driven vehicles to benefit autonomous vehicles will be detrimental to autonomous vehicle acceptance. Figure 1-11 shows the anticipated delay times as a function of traffic load under various mixes of human and autonomous vehicles. It shows that even a small percentage of human driven vehicles has a large impact.

![Figure 1-11. Performance of AIM FCFS light according to traffic composition](image)

The controller simulates the path of every vehicle to determine if it will accept the reservation or reject it. This works perfectly in the simulation but to do it in real life is far more complex and involves more variables, as for example; vehicle characteristics, road conditions and weather conditions. To work effectively in real life the bumper spaces on the vehicle have to be larger and this will lead to a slightly less efficiency than the simulation results [9].
Abrupt changes in G-forces due to turning, acceleration and braking can make it an uncomfortable experience for some passengers and this is not taken into consideration in the AIM system.

As far as the OSDI system by Zohdy and Rakha is concerned. They have mentioned several assumptions in their paper, namely

- All vehicles are autonomous i.e. there is no human driven vehicle
- The intersection is equipped with an intersection controller that has the ability and authority to control the movements of the vehicles
- All wireless connections are secure and support low latency communication
- All vehicles update their information to the controller each time step
- The intersection manager can change the speed profile of only one vehicle (the most critical one) at each time step.
- All vehicles are through vehicles (no turns) at intersections

Some of these assumptions are valid and are required for successful implementation of such a system. A low latency secure communication system with regular updates is the backbone to any intersection management project.

Other assumptions limit the capability of this system. The inability to process turning vehicles limits the application of the algorithm. Similar to Dresner & Stone’s AIM this algorithm only works with Autonomous Vehicles and will not work under a mixed traffic composition.

The assumption that the intersection manager will only change the speed profile of one vehicle may hurt the overall wait time as the algorithm does not consider the effect of changing the speed of one vehicle on the others.
CHAPTER 2
UF ALGORITHM

Overview

The UF algorithm is currently being developed by Zhuofei Li, a PhD Student at the Transport Research Center of Department of Civil Engineering at the University of Florida under the guidance of Dr. Lily Elefteriadou. It is a twofold approach which focuses on optimizing the signal phase and timing along with controlling the vehicles. The algorithm is in the development stage right now.

Literature Review

There are two general categories of traffic signal control optimization algorithms that consider the performance of signalized intersections based on the connectivity between vehicles and signal controllers. The first category seeks to optimize the intersection efficiency by improving signal control schemes based on the speed and location information from the approaching vehicles. These algorithms address spillback during oversaturated conditions, consider the breakup of vehicle platoons on the major street, and reduce the predicted future vehicle delays over a rolling horizon based on real-time data. These systems use short-range wireless transmitters in cars to communicate basic position information to the signal controller to achieve a better performance than the existing signal control scheme.

The second category of signal control optimization research focuses on improving the efficiency of the traffic stream by transmitting information from the signal to the vehicles. For example, the automobile company Audi developed a vehicle-to-infrastructure communication system named Travolution technology to help vehicles to communicate with traffic lights. Using this technology, the driver can decide what speed
to adopt so that it can arrive at the next intersection after the traffic light changes to green. It can also provide the amount of red time expected when the car is stopped at the light.

With respect to autonomous vehicles, previous work has mostly focused on the development of the technology itself. There has been research that has investigated the use of autonomous vehicles in an urban environment, but often these systems use simplified assumptions such as not having to identify signs and signals. Rather, it is assumed that this information is provided via road network data [12]

**Algorithm**

The algorithm will jointly optimize the signal control operations and vehicle paths. The algorithm is developed based on conventional signal timing, where the right of way is sequentially assigned to each phase. The algorithm provides optimal vehicle speeds (which can be presented to the driver of connected vehicles as a recommended speed, and to the autonomous vehicles as actual paths) and selects the phase pattern and duration to minimize the total waiting time of all the vehicles that travel through the intersection.

It is expected that a communication distance to the signal controller of at least 1,500 ft will be possible. Within this signal “influence area”, vehicles can effectively communicate with the signal controller. It is assumed that when the incoming vehicle is outside the signal influence area, it cannot obtain any signal control information. After the vehicle enters the intersection influence area, it may encounter three different scenarios based on the vehicle’s feasible traveling speed and the signal status at the intersection. Figures 2-1 through 2-3 shows the time-distance diagram for the three
different scenarios. The dashed blue area represents the speed region within which the vehicle can go through the intersection without stopping.

Figure 2-1. Scenario 1

The dashed red area represents the feasible speed region for the vehicle. If the red region overlaps with the blue region and the maximum speed of the overlapped region (recommended speed for this scenario) is higher than the current traveling speed, the vehicle has to accelerate to go through the intersection without stopping.

Figure 2-2. Scenario 2
If the red region overlaps with the blue region but the maximum speed of the overlapped region (recommended speed for this scenario) is smaller than the current traveling speed, the vehicle has to decelerate.

![Diagram of distance over time for Scenario 3](image)

Figure 2-3. Scenario 3

If the red region does not overlap with the blue region, the vehicle has to stop at the intersection, and a minimum speed is suggested. This basic idea will be enhanced to consider queues waiting at the stop bar, as well as a feasible acceleration and deceleration process.

For a given signal timing scheme, vehicles are able to adjust their speed to minimize the overall waiting time, and in this manner a minimum system waiting time (SWT) can be obtained. The minimum among those minimum SWT will be the optimum among all timing schemes. The basic idea used in this research is enumerating all the feasible timing schemes, calculating the SWT for each of them and choosing the one
that can minimize the SWT. The flow chart for this optimization procedure is presented in Figure 2-4.

![Flowchart](image)

**Figure 2-4. Flowchart for combining both optimization techniques**

The optimization results include the predicted optimum for the following optimization time period with the assumption that all the vehicles follow the recommendations provided by the controller. However, in reality, some of the vehicles may not follow the suggestion. Also, vehicles already inside the influence area will gradually leave the intersection and new vehicles will enter the influence area.
Therefore, optimization results are updated with a certain frequency using the rolling technique over a time horizon as illustrated in Figure 2-5

![Rolling Horizon Technique](image)

**Figure 2-5. Rolling Horizon Technique**

There are two key factors for this procedure: length of each optimization period and update frequency. The length of each optimization period should be determined based on the communication range between vehicles and the signal controller, and the average travelling speed of the vehicles. The update frequency should be determined based on the average speed of the vehicles and the magnitude of the influence area. It is better to guarantee that each optimization occurs while newly entering vehicles are still a certain distance away from the intersection, to maximize the effectiveness of the optimization.

**Benefits and Future Work**

Benefit of our algorithm over other algorithm is that we do not assume all vehicles are autonomous. We consider the data from both human driven and autonomous vehicle and determine optimum speed / signal timing which benefits every
vehicle. Human driven vehicles do not have to suffer longer wait times and there is no need to replace the existing infrastructure. This algorithm can be used as an intermediate solution before moving to 100% autonomous vehicles and replacing all the existing infrastructure.

In the future we plan to create a network of intersections controlled by our algorithm which will allow for better routing of vehicles in case of heavy traffic in certain areas and can also be used to synchronize the movement of vehicles which have same destination.

Because we are not assigning a permanent identifier to any vehicle, every intersection will treat the vehicle as a new entry. This makes it challenging to design a system that can route the vehicle from one point to another without compromising the privacy.
CHAPTER 3
PHYSICAL IMPLEMENTATION

No matter how sophisticated and efficient an algorithm might look in a computer simulation, it must be easily implementable to be successful. The UF algorithm does not make any assumptions about traffic composition. Additional information must be gathered from vehicles which will then be used to determine how the information is processed and what responses are given back to the vehicles.

The guiding philosophy is to gather the required information, at a level of required accuracy, but at a low cost and in a form-factor which requires little modification to the vehicle. Ideally, the entire unit would be battery-operated, small and light-weight enough so that it could be suction-cupped to the windshield similarly to many existing toll transponders.

Irrespective of vehicle type, certain information is needed from every vehicle: temporary identifier, vehicle position, speed, acceleration (for future use), lane of travel, orientation, destination and other previous recommendations given to the vehicle.

Depending on vehicle type the algorithm will either issue a recommendation about speed or will change the speed of an autonomous vehicle using Vehicle-to-Infrastructure (V2I) communication.

Information needed from the vehicle irrespective of their type is:

- Vehicle Location
- Vehicle Speed
- Lane of travel
- Direction of Approach
- Turn Status

To gather this data, many existing technologies will be used such as GPS, GLONASS, IMS, and DSRC which are explained in detail below.
GPS: Global Positioning System is the GNSS (Global National Satellite System) developed and maintained by U.S Department of Defense to overcome the limitations of existing systems [5]. A GPS receiver works on the principle of Trilateration. The GPS satellites periodically transmit information regarding time and satellite position. The receiver on earth uses this message to calculate distance of transmitter. Each of the distance and location define a sphere and the intersection of three or more sphere gives the location of the receiver. To an accurate result four or more satellites must be visible to the receiver at all times. Fewer satellites may also yield an accurate result in certain special cases. From any point on earth with clear vision to the sky 8-12 satellites are usually visible at all times. The larger the number of visible satellites yields more accurate results. Figure 3-1 shows a typical GPS receiver, the size of which has greatly reduced in recent years.

![Figure 3-1. GPS Receiver (u-blox 5 developed by u-blox)](image-url)
GLONASS: Globalnaya Navigatsionnaya Sputnikovaya Sistema is the Russian equivalent of GPS. It was developed as an alternative to GPS but now is used to supplement GPS. The basic workings of GLONASS is similar to GPS. As GLONASS was developed by Russia it has better availability in higher latitudes and can work in places where GPS can be problematic. GLONASS works on a different frequency than GPS. Combined receivers have been developed which can also work in urban jungles with fairly high level of accuracy. [6] Figure 3-2 shows a combined GPS/GLONASS receiver.

![Figure 3-2. GPS/GLONASS Combined Receiver](image)

IMU: An Inertial Measurement Unit is an electronic device that measures angular velocity and acceleration using accelerometers and gyroscopes. They may or may not include a magnetometer (which will be discussed later in the chapter). An IMU works by
detecting the acceleration using one or more accelerometers and detects changes in pitch, roll and yaw using one or more gyroscopes.

They are used in Unmanned Air Vehicles (UAVs) and Unmanned Ground Vehicles (UGVs) and other autonomous vehicles along with GPS and can provide dead reckoning in case a position cannot be obtained by GPS. However dead reckoning is subject to cumulative errors and cannot be used for extended periods of time. Figure 3-3 shows a typical IMU.

Figure 3-3. Inertial Measurement Sensor (Razor 9 DOF IMU)

A magnetometer is an instrument used to measure the strength and direction of magnetic fields. Magnetometers can be of various types, for example Hall Effect, Magnetoresistive, Rotating Coil, or Flux Gate. Magnetometers are also available in smart phones [7]. Figure 3-4 shows a typical magnetometer
Metal Detector: It is device that responds to presence of metal objects which are not in plain sight. They are used to find metal objects buried deep in soil and also to find hidden objects such as knives and guns at Security checkpoints. A metal detector consists of 3 components, namely [8]:

- Control Box – contains the circuit/processor
- Shaft – connects the other two parts
- Search Coil – the actual part which senses the metal

There are 3 basic types of metal detectors, namely:

- Very Low Frequency (VLF)
- Pulse Induction
- Beat-frequency Oscillation (BFO)
Very Low Frequency: There are two coils in a VLF metal detector, a transmitting coil and a receiving coil. The receiving coil is shielded from the receiving coil but it is not shielded from the reflected fields. When the receiver coil passes over an object, the object gives off a magnetic field. This causes a small electric current to travel through the coil. [8] The coil amplifies the frequency and sends it to the control box of the metal detector, where sensors analyze the signal. Figure 3-5 shows a typical VLF metal detector.

![Image of VLF Metal Detector](image)

Figure 3-5. VLF Metal Detector

Pulse Induction: This is a less common form of a metal detector, Unlike a VLF system it only uses one coil instead of two. This type of metal detector sends bursts of
energy to the coil. The pulse generates a brief magnetic field. At the end of the pulse, there is reversal in the magnetic field’s polarity and it collapses very suddenly, resulting in a sharp electrical spike. This spike lasts a few microseconds and causes another current to run through the coil. This current is called the reflected pulse and is extremely short, lasting only about 30 microseconds. [8] If the metal detector is over a metal object, the pulse creates an opposite magnetic field in the object. When the pulse’s magnetic field collapses, causing the reflected pulse, the magnetic field of the object makes it take longer for the reflected pulse to completely disappear. A sampling circuit then detects the difference between the times taken for the pulse to disappear which indicates presence of metal.

BFO: Beat frequency oscillator is the most common form of metal detector. In a BFO system, there are two coils of wire. One large coil is in the search head, and a smaller coil is located inside the control box. Each coil is connected to an oscillator that generates thousands of pulses of current per second. The frequency of these pulses is slightly offset between the two coils. If the coil in the search head passes over a metal object, the magnetic field caused by the current flowing through the coil creates a magnetic field around the object. The object’s magnetic field interferes with the frequency of the radio waves generated by the search-head coil. As the frequency deviates from the frequency of the coil in the control box, the audible beats change in duration and tone [8].

The intent is to use a Pulse Induction type metal detector to detect road markings. Small discs of metals will be secured under the surface of the road in specific
patterns which will the vehicle to determine the lane of travel. This is shown in Figure 3-6.

Figure 3-6. Sample Intersection showing Lane Marker Locations

The Figure 3-7 shows the different parts of the proposed marker. The assembly consists of the metal disc, an anchor both, bolt pin and a cap with security head. The anchor bolt and security cap ensures that the marker cannot be removed for its position in case of theft or vandalism.
Figure 3-7. Sample Marker Assembly (Bolt, Marker, Pin, Security Cap/Nut)
DSRC: Dedicated short-range communications are one-way or two-way short- to medium-range wireless communication channels specifically designed for automotive use. In October 1999, the United States Federal Communications Commission (FCC) allocated in the USA 75MHz of spectrum in the 5.9GHz band for DSRC to be used by Intelligent Transportation Systems. [9]. It uses IEEE 802.11p as its groundwork. It is capable of providing a range of up to 1 kilometer and vehicle speeds up to 60 mph. The data rate is in range of 3-27Mbs with latency less than 50 milliseconds.

802.11p: IEEE 802.11p is an approved amendment to the IEEE 802.11 standard. It adds wireless access to vehicular environments and is required to support Intelligent Transportation Systems (ITS) applications. It operated in the licensed ITS band of 5.9 GHz (5.85-5.925 GHz) [10].

The setup to use DSRC in this project includes an On Board Unit (OBU) and a Road Side Unit (RSU). There will be 1-5 RSU installed around the intersection depending on the geometry and range (Figure 3-8) and one OBU per complaint vehicle.

Figure 3-8. Sample Intersection showing location of Road Side Units
Human driven vehicles will be sent a recommended speed and lane (in future work) along with time to signal change. Autonomous vehicle speed will be changed by the intersection controller. The intersection controller will also run a simulation of the path of the entire vehicle based on data from the vehicles so position extrapolated in case of missing packet or other transmission fault.

**Autonomous Vehicles**

Autonomous vehicles already have certain sensors installed in them and data from these sensors can be used for the system.

For location, a GPS Sensor will be used but most GPS sensors are not accurate enough for the purpose for detecting the lane of travel with a high level of certainty. There are other ways to detect the lane which were initially thought but dropped as they were not accurate enough for this project e.g., Received Signal Strength Indicator (RSSI) Triangulation (explained in Appendix A).

The only two options available here are either to use a very accurate GPS receiver or to have magmatic markings in the lanes which can be read by a coil attached to the base of the vehicle. GPS receivers can be quite accurate when there is a clear line of sight to the satellites but they are ineffective when used in an urban jungle like Manhattan. Multi-path errors render the data unfit for this project. However the newer GPS/GLONASS combined receivers are claimed to have better accuracy in urban jungles. One such system that is available is the Garmin GLO GPS GLONASS receiver. Garmin claims that this receiver has an accuracy of 3 meters. Garmin GLO is ideal to navigate in an urban environment but it is still not accurate enough to sense lane of travel and lane changes. Due to this reason it was decided to use lane markers and sense them to determine the lane of travel.
Small metal discs will be embedded 3-4 inches deep in the road surface at predetermined intervals and patterns. For example, the lane closest to the median can have one marker after every say 10 meters and the next lane can have two markers after each 10 meters and the lane right to them can have three markers after every 10 meters. There can also be a special pattern of markers for turn lanes. The vehicle will be equipped with a metal detector coil which will be installed under the chassis. The metal detector will detect the presence of marker patterns and this information can be used to sense the lane as well as any lane change accurately.

There are a few choices for sensing the speed and acceleration. One can either tap into the speedometer to get the speed of the vehicle or can use the GPS way points to calculate the speed. Additionally the lane markers can be used for calculating the speed. GPS seems to the easier solution but it suffers from the multipath problem in urban environments. Multipath error can lead to an error in speed calculation. Using the speedometer seems to be a better solution but it will require modification to the vehicle. Since we are talking about an autonomous vehicle, all the tools necessary to extract the speed information from the vehicle will be available.

For calculating the acceleration data from the vehicle an IMS device will be used which will report all three axial accelerations along with yaw, pitch, and roll rates. The algorithm however does not require this information but it can be used to extrapolate the position of vehicles in case of loss of transmission. This information can be used in future algorithms to maximize safe turning speeds for larger vehicles.

The last and most important piece of information which sets this system apart from the one developed by Virginia Tech is the use of turn signals. Since turning
vehicles are also considered in the UF algorithm. It is necessary to extract this information. This can be done by tapping into the CAN BUS of the vehicle or by using information from a Navigation Unit/Map.

This extracted information will then be packaged into the format required for transmission and sent to the Intersection Manager which will run its calculations and send the optimal speed and lane information back to the vehicle. This information will be used to change the speed of the vehicle and lane (if required). This process will be repeated at predetermined intervals till the vehicle has cleared the intersection.

**Human Driven Vehicles**

Application of such a system in a Human Driven Vehicle is more complicated and requires more effort as a human driven vehicle does not have the necessary hardware unlike their autonomous counterpart. Similar to the autonomous vehicle the location information can be obtained from a GPS/GLONASS sensor and it can be differentiated to obtain speed information. Information about acceleration and orientation can be obtained from an IMS device and heading can be obtained from a magnetometer so the algorithm can differentiate between vehicles approaching and leaving the intersection.

The main issue with human driven vehicles is to obtain the turn indication. One can tap into the electrical system of the vehicle to sense the use of turn signals or attach a small micro switch onto the turn stalk that will report the turn direction. This system works on the assumption that human driver will use the turn indicator every time he/she has to make a turn.

The lane data will be obtained using a marker and metal detector as explained with autonomous vehicles. After the data has been sent to the Intersection Manager the
Intersection Manager will send back the recommended speed / lane along with Signal Timing information. This will help the driver to make adjustments as he/she deems best.
CHAPTER 7
FUTURE WORK

This system is far from perfect and does not account for many factors such as vehicle type or vehicle capacity. In the future more variables can be accounted for in the algorithm. One can assign priority based on vehicle type such as giving a higher weightage to a bus in an urban environment. This can also be used to give priority to laden trucks at rural intersections or at ramps.

The system at present is only designed to work at one intersection. As there is no unique permanent identifier issued to any vehicle because of privacy issues. Work can be done in designing a network of intersection managers which can optimize the flow of traffic on a city or block level w/o assigning a permanent identifier to a vehicle.

Lane sensing can be developed using Markov-Based Lane Positioning Using Inter-vehicle Communication [11]. This will relieve us from having to install markers or to rely on GPS data. Under this system the vehicles will communicate with each other and using each other’s GPS data determine the lane of travel [11].
APPENDIX A
RSSI BASED POSITION ESTIMATION

This is the sample algorithm we used to determine the effects of errors in RSSI based triangulation.

\[
P_1 = [0, 0, 0]' \\
P_2 = [10, 0, 0]' \\
P_3 = [0, 10, 0]' \\
e = .02 \\
r_1 = \sqrt{200} \\
r_2 = \sqrt{100+100*e} \\
r_3 = \sqrt{100} \\
ex = (p_2-p_1) \\
ex = ex / (\sqrt{ex(1,1)^2+ex(2,1)^2+ex(3,1)^2}) \\
i = \text{dot} (ex, (p_3-p_1)) \\
Ey = (p_3-p_1-i*ex) \\
ey = ey / (\sqrt{ey(1,1)^2+ey(2,1)^2+ey(3,1)^2}) \\
ez = \text{cross} (ex, ey) \\
d = p_2-p_1 \\
d = \sqrt{d(1,1)^2+d(2,1)^2+d(3,1)^2} \\
j = \text{dot} (ey, (p_3-p_1)) \\
x = (r_1^2-r_2^2+d^2) / (2*d) \\
y = (r_1^2-r_3^2+i^2+j^2) / (2*j) - i*x / j \\
z_1 = \sqrt{r_1^2-x^2-y^2} \\
z_2 = -\sqrt{r_1^2-x^2-y^2} \\
xv = (x-10)*10 \\
yv = (y-10)*10
\]

\text{p1, p2, p3 are simulated locations of 3 Transmitters with [0, 0, 0] being the center of the intersection. E is the error in distance estimate from RSSI values. xv and yv are the error in position we obtained from the calculation.}
Based on our experiment we are able to determine certain positions of transmitters which gave us high tolerance for errors in one direction but the error in other direction became worse.
Figure A-2. Location of Transmitter and Receiver

The table below tells %age error in position caused by error in converted distance

Table A-1. Effect of error in distance on position

<table>
<thead>
<tr>
<th>%age error in D1</th>
<th>%age error in X</th>
<th>%age error in Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.5</td>
<td>.5</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>20</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>
In certain orientations the error in one direction remains 0 while error in other direction would become huge. This is possible because we were assuming the x-y plane is flat.

Table A-2. Effect of error in distance on position in special orientation

<table>
<thead>
<tr>
<th>%age error in D1</th>
<th>%age error in X</th>
<th>%age error in Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.5</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>40</td>
</tr>
<tr>
<td>10</td>
<td>15</td>
<td>100</td>
</tr>
<tr>
<td>20</td>
<td>30</td>
<td>200</td>
</tr>
</tbody>
</table>

Due to such large %age errors and distances involved. RSSI Trilateration cannot be used to accurately calculate position of a vehicle. This is due to the fact that the receiver is outside the triangle formed by the transmitters.
Prior to working with the Civil engineering department and using their algorithm, I tried to develop an algorithm for all way STOP sign based intersections which would allow two cars to cross the intersection at the same time when their path was not intersecting.

The program was written in parts as a function, the main program just runs them on parallel threads. Any increase in efficiency has not been calculated. The physical implementation is same as explained in Chapter 3.

```matlab
function [b]=define
clear b
b.tag='NY2444446'
b.dirin=2
b.dirout=4
b.right=0;
b.left=1;
b.delay=1
b.stamp=clock
function [a]=go(a)
[r,c]=size(a);
if c==0
    display('Empty Stack')
else
    if c==1
        a=subs(a,1);
        display('Car sent delay initiated')
    else
        if a(1).dirin==a(2).dirin
            a=subs(a,1);
            display('Car sent delay initiated')
    else
        if a(1).dirin==a(2).dirout && a(2).dirin==a(1).dirout
            a=subs(a,1);
            display('No Delay used as path are parallel')
            display('Car Sent No Delay')
```
a=subs(a,1);
display('Car2 Sent - Delay')

else

    if a(1).right==1 && a(2).right==1
        a=subs(a,1);
display('No Delay used both are turning right and hence have no intersection')
display('Car1 Sent No Delay')
a=subs(a,1);
display('Car2 Sent - Delay')
else

        if a(1).right==0 || a(1).left==0 || a(2).right==1 || a(1).dirout~=a(2).dirout
            a=subs(a,1);
display('One is going straight and 2 is turning right with exit not common')
display('Car1 Sent No Delay')
a=subs(a,1);
display('Car2 Sent - Delay')
else

            if a(2).right==0 || a(2).left==0 || a(1).right==1 || a(1).dirout~=a(2).dirout
                a=subs(a,1);
display('two is going straight and 1 is turning right with exit not common')
display('Car1 Sent No Delay')
a=subs(a,1);
display('Car2 Sent - Delay')
else

                a=subs(a,1);
display('Car sent delay initiated')

end
function [a]=add(a,tag,dirin,left,right,delay)
[r,c]=size(a);

if left==1
    if dirin~=4;  % IF left then where to exit
        dirout=dirin+1;
    else
        dirout=1;
    end
end
if right==1
    if dirin~=1;  % IF right then where to exit
        dirout=dirin-1;
    else
        dirout=4;
    end
end
if left==0 && right==0
    if dirin==1 || dirin==2  % IF straight then where to exit
        dirout=dirin+2;
    end
    if dirin==4
        dirout=2;
    end
    if dirin==3
        dirout=1;
    end
end

a(c+1).tag=tag;
a(c+1).dirin=dirin;
a(c+1).dirout=dirout;
a(c+1).left=left;
a(c+1).right=right;
a(c+1).delay=delay;
a(c+1).stamp=clock;

function [a]=subs(a,n)
[r,c]=size(a);
for i=n:c-1,
a(i).tag = a(i+1).tag;
a(i).dirin = a(i+1).dirin;
a(i).dirout = a(i+1).dirout;
a(i).delay = a(i+1).delay;
a(i).stamp = a(i+1).stamp;
a(i).left = a(i+1).left;
a(i).right = a(i+1).right;

end

Another approach that we used was to detect presence of other cars at the stop sign controlled intersection using LIDAR sensors and comparing the distance between points that were returned and comparing them with existing data to check for presence of other vehicles and proceed according to the order the cars were sensed.
REFERENCES


BIOGRAPHICAL SKETCH

Maninder Singh was born in Union Territory of Chandigarh, India. He received his Bachelor of Technology degree from the Punjabi University, INDIA in 2011. He worked for Honda Motorcycle and Scooter India as an Engineering Intern for 5 months in Supplier and Quality Development before joining University of Florida for Masters of Science in Mechanical Engineering. He joined the Center for Intelligent Machines and Robotics under the guidance of Dr. Carl Crane in early 2012. He worked closely with the Transportation Research Center at the University of Florida under guidance of Dr. Lily Elefteriadou during his master’s thesis.

He plans to pursue a doctoral degree in Mechanical Engineering in Near Future. His research interests include Autonomous Vehicles, Sensors, and Industrial/Process Automation.