Palestine Polytechnic University
Deanship of Graduate Studies and Scientific Research

Agent Based Road Traffic Congestion Management Using Vehicle Horn Model

Submitted by

Alaa Asem Aljabari

In partial fulfillment of requirements for the degree of Master in Informatics

January, 2013

The undersigned hereby certify that they have read and recommend to the Deanship of Graduate Studies and Scientific Research at Palestine Polytechnic University the acceptance of a thesis entitled *"Agent Based Road Traffic Congestion Management Using Vehicle Horn Model"* submitted by Alaa Aljabari in partial fulfillment of the requirements for the degree of Master in Informatics.

Graduate Advisory Committee

Dr. Adel Taweel (Supervisor)

Signature: Radwan Date: 17/3/2013

Dr. Amal Al Dweik (Internal Examiner)

Palestine Polytechnic University, Palestine

Signature:__________ Date: 24/3/2013

Dr. Rashid Jayousi (External Examiner)

Al-Quds University, Palestine

Signature: R. Jayousi Date: 17/3/2013

Thesis approved by

Dr. Sameer Hanna

Dean of Graduate Studies and Scientific Research

Palestine Polytechnic University, Palestine

Signature:__________ Date: 24.03.2013

Abstract

Traffic congestion is one of the most important problems we face in our daily life. This problem has a huge effect on economy and environment. The total of congestion cost in America in 2010 reached to 101 billion dollar and it is expected to reach to 175 billion dollar in 2020 [1]. Despite of many research in this field the problem still exists all over the world.

The new domain for solving this problem is using agent based technology, which can model the traffic network as agents, these agents can communicate, cooperate to achieve the optimal performance of the network.

Our thesis proposed a solution for this problem based on agent technology. We use various agents in our model which include lane agent, vehicle agent and traffic light agent. We use lane agent for every lane of the network to compute the weight of the lane and send it to traffic light agent. This weight depends on a new model called horn model. The horn is the sound produced by vehicles to give an indication that green sign is needed, this sound increase with waiting time and decrease as the distance of waiting vehicles from traffic light increase.

Traffic light agents use the congestion factor and weight it receive from lane agents to optimize traffic light signal. Optimization is done by giving the needed time for every lane according to the number of waiting vehicles and to keep track of the waiting time of other vehicles in other lanes by using lane weight. This solution can give a dynamic cycle time according to real time traffic data. Route guidance system based on congestion factor is used also to stop sending vehicles to congestion area. Traffic light agents communicate to

solve the congestion in specific junction by reducing the amount of vehicles sent to that junction and increasing green time of congestion lane.

We use simulation to evaluate our model. We compare our model with fixed traffic light timing and ANT colony optimization algorithm used to solve road congestion. Our model give the best results under various traffic light condition.

Declaration

I declare that the master thesis entitled *"Agent Based Road Traffic Congestion Management Using Vehicle Horn Model"* is my own original work, and hereby certify that unless stated, all work contained within this thesis is my own independent research and has not been submitted for the award of any other degree at any institution, except where due acknowledgement is made in the text.

Alaa Aljabari

Signature:________________________ Date:_________

Statement of Permission to Use

In presenting this thesis in partial fulfillment of the requirements for the master degree in Informatics at Palestine Polytechnic University, I agree that the library shall make it available to borrowers under rules of the library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of the source is made.

Permission for extensive quotation from, reproduction, or publication of this thesis may be granted by my main supervisor, or in his absence, by the Dean of Graduate Studies and Scientific Research when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Alaa Aljabari

Signature:____________________ Date:________

Dedication

For my father who supported me each step in the way.

Acknowledgment

I would like to express the deepest appreciation to my supervisor, Dr. Adel Taweel, for his efforts with me throughout my thesis and without him this work would not have been completed.

I would like to thank my committee chair, for their valuable comments and questions to improve this work.

In addition, many thanks go to my friend Eng. Ghannam Jabari for his advice and support from the early stages of my thesis.

Table of Contents

List of Figures

List of Tables

Chapter 1

Introduction

Every day we face the problem of traffic jam at different points of the traffic network. This problem gets worse as the number of cars and population increase. *The Technical Report of The United Nation Population Fund* showed that more than half of the worlds population *around 3.3 billion people* live in an urban area and the balance of people continues shifting to the cities [3]. This cause traffic congestion in urban cities to become a challenging problem. According to the *2011 Urban Mobility Report* which is issued by the *Texsas Transportation Institute* [1] American in urban areas had to drive 4.8 billion hours more because of traffic congestion. Furthermore, an extra of 1.9 billion gallons of fuel were consumed. The total congestion cost in 2010 reached to 101 billion dollars. The report expected that in 2015 national congestion cost will grow from 101 billion to 133 billion dollars and 175 billion dollars in 2020. The delay will grow from 4.8 billion hours to 6.1 billion hours in 2015 and 7.7 billion hours in 2020.

The other side of this problem includes social problems, environmental pollution, health problems, stress and other which may not be limited.

Many researchers work to solve congestion problems, and many strategies have been examined. The new domain for solving congestion is to develop an agent based traffic management system to cooperate and coordinate to solve congestion problems. In our research we review the problem of road traffic congestion by studying the research papers in this field, this literature review give us a good understanding of the reasons behind traffic congestion. We developed a simulation model using Netlogo simulation platform, this simulation model traffic flow for two junctions. We first use this model to understand the factors that cause traffic congestion. Then we use simulation to examine many solutions for traffic congestion and compare it with existing techniques.

Our solution depends on modeling traffic network as agents, these agents can communicate, coordinate and cooperate to smooth the movement of vehicles across the network. In our model we suppose that vehicle agent can give its position and speed in real time to lane agent. Lane agent is responsible for estimating the weight of the lane using horn indicator. This horn depends on the waiting time vehicles spent in the waiting queue; we suppose that waiting vehicles honks while stopping in the waiting queue, this horn sound increases with waiting time and decreases with distance.

The traffic light agent receives the weight and the congestion factor for every lane from its agent. The congestion factor is used to estimate the green time needed. Traffic light switching takes place if the green time given to specific lane is completed or the weight of other red light lane reaches to specific threshold. Traffic light agent coordinates to stop sending vehicles to congested intersection and to increase green time in a specific direction. Also, lane agents can communicate with vehicle agent to inform it of congestion route and ask it to reroute

1.1 Thesis Contributions

This master thesis, proposes a new study of road congestion factors presented in chapter 3. During our study of road congestion factors we focus on accidents, traffic flow, working zone and poor traffic light timing. According to our study we classify road congestion factors into two categories: fast impact congestion factors and slow impact congestion factors.

We propose a new model for optimizing traffic light signal called horn model presented in chapter 4. This model can optimize traffic light signal depending on vehicles waiting time and vehicle count. The horn model is taken from the idea of using horn sound as indicator. In our model we use vehicles waiting time and distance for generating this indicator. traffic light agent use this indicator with waiting vehicle count in optimizing traffic light signal.

We also present a new agent based model presented in chapter 4 for solving the problem of road congestion. We use three agents(vehicle agent, traffic light agent and lane agent). We identify how these agents cooperate and communicate to solve the problem of road congestion and how they use the horn model to optimize traffic light signal. The effectiveness of the developed horn model combined with the multi-agent system are evaluated in chapter 5 on a two junctions using Netlogo simulation.

We compare our algorithm performance with two previous traffic management systems which is fixed control plan and using the idea of an ANT colony to solve the problem of road congestion [4]. We simulate these two solutions and we compare our algorithm with these two models.

1.2 Thesis Organization

Chapter 2 provides a literature review of the thesis. Chapter 3 provides a study of congestion factors that causes traffic congestion, which is extracted from literature review and from our simulations. Chapter 4 describes the design of our agent based traffic management system which is depending on horn model. Chapter 5 summarizes our simulation and results. Chapter 6 gives a brief conclusion from our study.

Chapter 2

Literature Review

In recent years, there has been a fast growing interest in solving the problem of road traffic congestion as this problem has a huge effect on the economy. This problem is complex, geographically distributed and dynamic. This chapter reviews the various techniques researchers used in solving the problem of road traffic congestion.

In section 2.1 we present the various existing traffic congestion management techniques, this includes the various models used in collecting traffic data and the optimization techniques used in optimizing traffic light signal. we also review the route guidance systems. In section 2.2 we review the principle of agent and how it is used in transportation domain.

2.1 Existing Congestion Management Techniques

The traditional way in controlling traffic light signal is to give a fixed cycle time for the whole intersection and to divide this cycle between the lanes of the intersection according to historical volume. This way does not take into account the changes of traffic flow in real time.

Existing techniques in solving road congestion involve collecting real time traffic data and optimizing traffic light signal according to these data. Route guidance systems also built depending on real time traffic data.

2.1.1 Collecting Real Time Traffic Data

Various monitoring systems are used to collect real time traffic data, these systems include:

Sensors

Sensors are widely used to monitor road traffic network [5–10]. In [7] wireless sensors is used to detect the sound of emergency vehicles(police, ambulance, fire brigade) and to communicate wirelessly with traffic light control system, these sensors may confuse different sounds and make mistakes. **Sensors** are commonly used at intersections to estimate the queue length, this make sensors limited to give a global view of the network or predict the future traffic data. If we want to wider the area which is covered by sensors, we need to install a large number of sensors; this will become expensive to install and maintain. In [5] 4-sensors are installed in the waiting queue to calculate the amount of waiting vehicles. These sensors are distributed at different distances from traffic light signal and every sensor is given different weight according to its distance from the traffic light. Another sensor is installed in the destination lane to examine if it can receive more vehicles. waiting queue sensors can give the number of vehicles in the waiting queue, but it can't give the amount of time spent by each vehicle in the waiting queue. Our approach will keep track of the time vehicles spent in the waiting queue, this will give aging to low flow lanes.

Two indicator loops are used in [9] to monitor the queue length of the intersection, the first is installed at stop line and the other is 120 meters away from the intersection; this can monitor 20 waiting vehicles. Traffic light timing is controlled according to sensors reading. Queue length is estimated in [11] using two inductive loops and its reading is sent to fuzzy control to adjust traffic light timing. If we divide the traffic light cycle time between different lanes according to inductive loops reading, we can't deal with the changes that occurred in red light lanes traffic data after the green time is completed. Our approach will use a dynamic cycle time at real time. Every time we want to give green time, we will compute the new cycle time and green time.

Radio Frequency Identification Technology(RFID)

The RFID reader is installed beside the traffic light to detect the vehicles which have RFID transmitter [5,12,13]. Some techniques suppose that RFID transmitter is installed in every vehicle [12], others install RFID tag in emergency vehicles only [5].

GPS Monitoring System

Global positioning system (GPS) is a system that can receive its position from different satellites. A GPS receiver can give its three dimensional position if it receive its position from four different satellites. GPS system can calculate its speed and direction once it receive its position [14]. GPS tracking is a new technology to monitor traffic data, if we install a GPS tracking device in vehicles, this device can give the position and speed of the vehicles in real time. From this information we can know the real time traffic data [4, 15–18]. In [17] GPS tracking module is installed in every vehicle in the system to collect real time traffic data and send these data across the GPRS network to control station to decide the charge of the road segment. In our model, we also suppose that GPS tracking module is installed in every vehicle and we use the GPRS network to communicate with these tracking modules. The use of GPS tracking can reduce the cost of installing and maintenance of sensors in every lane and it can give a global view of traffic network. This technology is also available in mobile phones, which could be used as tracking devices.

Intelligent Car

In [19] intelligent car is used to collect data about the other cars around it such as acceleration, deceleration and speed. These data is used to influence the speed of the rest of the cars. Some vehicles have wireless capabilities to send its speed and location to traffic light, traffic light will send these data to a centralized server which will compute the congestion degree of every segment of the network. Congestion degree is sent back to vehicles, which will use it to choose the suitable route [20]. Intelligent vehicles can communicate with each other, vehicle to vehicle communication is used in [21]. Intelligent vehicle estimates the driving time it spent and compare it with ideal travel time to compute the congestion factor of the lane. This congestion factor is sent to vehicles in the same region, these vehicles will use it to choose the best route. To use intelligent cars we need to install large number of these cars in traffic network, this solution is very expensive and hard to implement.

2.1.2 Optimizing Traffic Light Signal

According to Urban Mobility Report [1], one of the seven causes of traffic congestion is poor traffic light signal timing. Various techniques have been used to optimize traffic light signal which includes:

Queue Length Optimization Techniques

The monitoring system is used to detect the length of waiting vehicles in the waiting queue, this length is used by traffic light to give the appropriate green time for each lane in the intersection [18, 22, 23]. In [18] the queue length is estimated from the data extracted from GPS tracking devices installed in every vehicle. Longest Queue First Maximum Weight Matching(LQF-MWM) is used for scheduling signal at an isolated intersection. This algorithm also gives the highest weight to some vehicles like ambulances. Longest queue first may cause low flow lanes to wait too long time, it does not take into account the waiting time vehicles spent in the waiting queue. In [24] the count number of red light cars lane is used to optimize the traffic light signal. If this count reaches to specific threshold, green light is given to that lane. Minimum green time is added to prevent switching before that time. This technique will also force low traffic flow lanes to wait too long time. In our solution we will optimize traffic light signal according to real time queue data and we will use waiting time as an indicator which must be limited. If this waiting time is exceed specific threshold, green signal must be given to that lane.

Fuzzy Logic Optimization Techniques

Fuzzy control is used by many traffic light control devices [7,8,11,12,25,26]. In [11] fuzzy control is a controller which receives measurements of incoming traffic and decide the extended length of green time that must be added to assigned green time. Other traffic light controllers use fuzzy to decide the green length [25]. The input to fuzzy controller is the distance covered by vehicles and total free space between vehicles on the road, the output is the length of green signal which may be very less, less, medium or large. Research done in [26] presented the concept of main urgent lane and minor urgent lane. Main urgent lane is the highest degree urgent lane which must take the green signal, the other minor urgent lanes which are compatible with main urgent lane is given also green signal. Fuzzy logic is used to compute the degree of urgent. The input to fuzzy is the time of red signal, congestion degree and the number of vehicles that are waiting in the queue; this number is extracted from two detectors installed in every lane. The output is the urgent degree of red signal lanes.

Fuzzy control is used in [7] to minimize traffic flow on the route of emergency vehicles, so that they can pass with their maximum speed and their collision avoided. This minimization in traffic flow may cause other lanes to become bottleneck. Fuzzy control is used also in [8] to optimize the traffic light signal. The input variables of the fuzzy controller are vehicles waiting time and queue length, the output is the timing of traffic light signals. Optimization of isolated intersection traffic light may cause other intersections to become congestion. fuzzy control has a drawback that it does not coordinate between traffic light signals. Agents can communicate and coordinate to achieve optimal network performance. In our approach, traffic light agents will coordinate to achieve optimal solution.

Machine Learning Optimization Techniques

"An experienced taxi driver relying on his knowledge about the traffic change in different time, can more easily find out more suitable path than the common driver" [27]. So learning traffic light to take benefit of the historical data is a good way in optimizing traffic light signal. Back propagation neural network is used in [27] to expect the driving speed in future. The input of the neural network is the driving speed at the same five minute time of the week and the current driving speed in the current time period. The output of the neural network is the expected driving speed at time (t + 1), this expected speed is used to choose the optimal path with fastest driving speed. Depending on historical data can't give an accurate solution. Traffic data is dynamic and the speed of driving depends on many factors. Our approach will depend on real time traffic data to choose the best route.

Back propagation neural network is used in [23] to decide the amount of extended green time to add to the current green time. The input to the neural network is queue length and cycle length ratio, the output is the extended green time. In [28] a cluster of the same historical data traffic demand is constructed, and an optimal traffic light plan is calculated for each cluster. Current traffic flow is mapped to one of the historical clusters, and its time plan is implemented. determining to which cluster the current traffic flow belong is another problem. Neural network is used to determine the relationship between traffic demand and their timing, input of the neural is the volume(vehicle per hour along each approach), the output is the cycle length, splits and offset.

Using reinforcement learning can help in transportation domain. Reinforcement learning can communicate with the environment and estimate the reward from applying specific control action [29]. In [29] three different states are examined, these states are the arrival of vehicles at a red light, queue length and cumulative delay. The action is a variable phasing sequence and the **reward** of the RL algorithm is the saving in the delay time. The results show that Q-learning reduce the total delay by 36% compare with the fixed signal plane.

2.1.3 Route Guidance Systems

Route guidance systems are classified into two categories according to [30] :

Infrastructure-based route guidance system

These systems depend on the status of traffic flow in determining the best route. Some systems are centralized which depend on centralized server to receive the real time traffic data from monitoring systems and estimate the best route and send it back to vehicles. Decentralized systems will depends on vehicles to decide its best route after receiving its own monitoring data.

Infrastructure-less Route Guidance Systems

Without the need for infrastructure monitoring system, vehicles need a computer system which has maps of the road network, vehicles chooses its destination. The best route is chosen according to static criteria such as shortest path.

Many ideas has been used in route guidance systems. Some route guidance systems depend on server to estimate the fastest pass [13, 27], this path is calculated depending on data collected from RFID tag installed in vehicles. After estimating the fastest path, server sends it back to vehicles [13]. Other servers compute the shortest path after the driver choose his destination. Every shortest path has a fitness function depend on travel time, congestion factor and fuel consumption. The path with best fitness function is chosen by the server and sent back to vehicles [13]. Evaluating the shortest path according to fitness function is a good idea because if we depend on the shortest path only, all vehicles will take this path making it congestion.

Informing driver on congested route in real time can help them avoid stuck in congested areas. Global System for Mobile communication (GSM) message is used in [17] to inform drivers of congestion route. Congestion degree is used in [20] to choose the best route. Centralized server receives the speed and location from vehicles equipped with wireless capabilities, from these information servers compute congestion degree for every lane in the network and send it to vehicles.

In [31] exploration ANT is used to travel through the network and gather information about possible routes. The best route is chosen according to route length, fuel consumption and total travel time of exploration ANT. These ANTs is modeled in [4] as vehicles, these vehicles are equipped with GPS tracking device which can give the exact position of every vehicle in the network. The number of vehicles in every lane is used to calculate the congestion factor which is the same as pheromone concentration, this pheromone concentration is used to choose the best route.

In our model, congestion factor is used also to ask drivers to change their route at specific locations. If some lane has high congestion degree we need to stop sending vehicles to that location. This will help in reducing congestion. For some drivers, this solution may force them to take longer lane, but we concentrate on the benefit of the overall system not a specific vehicle.

2.2 Agent Technology in Transportation Domain

2.2.1 Agent Technology

"'Agent is anything that can be viewed as perceiving its environment through sensors and acting upon that environment through effectors"' [32]. This agent can take its own decision without any help from outside [33].

2.2.2 Agent Properties

From the definition of agent we can understand many properties of the agent which includes:

1. **Autonomy:** Agents ability to control its behavior according to its knowledge without any help from outside [34–36].

2. **Responsiveness:** The ability to quickly respond to the environment and other agents. The response is faster than fastest change in the environment [34, 37].

3. **Social Abilities:** Interact, collaborate and communicate with other agents or human [34, 37].

4. **Learning:** The ability to assess its action and learn from errors [34].

5. **Collaborative:** Agents collaborate with each other to achieve a global goal [37].

2.2.3 Agent Classifications

Nwana [38] identify six types of agents:

1. **Collaborative Agent:** This will help agent to solve too large problems. It allows multiple systems to connect and operate with each others, also it can help in gathering distributed information in a heterogeneous network. Collaborative will give us the ability to take the benefit from distributed systems.

2. **Interface Agent:** Support user who uses complex applications. This agent learns what the needs of the user and change its interface according to user needs.

3. **Mobile Agents:** They are intelligent software that can travel across the network and perform specific task for the user and return back to the used with the needed information. This way of communication can reduce the cost of communication and coordination and it can give a new way in the design process in general.

4. **Information Agent:** Collect information from many distributed environments and make desired manipulation of this information according to user needs.

5. **Reactive Agents:** They respond in a stimulus response manner to the present state of the environment in which they are embedded.

6. **Hybrid Agents:** It is a combination of two or more agent philosophies. These philosophies include mobile philosophy, collaborative philosophy, interface philosophy, etc.

2.2.4 Multi-Agent System

Multi-agent systems (MAS) is a distributed system that consists of a number of autonomous agents, communicating, coordinating and cooperating with each other in a heterogeneous environment [35].

MAS Architectures :

According to the literature [35], four main MAS organizations exist:

1. **Hierarchical MAS :** in which agents communicate according to a hierarchical organization. The disadvantage of this architectural type is the reduction in autonomy of individual agents, as the lower levels of the MAS depend on the higher levels. However, this architecture could reduce the required communications as well as individual agent complexity.

2. **Flat MAS :** where any agent may interact with any other agent in the MAS. These provide the greatest autonomy, but could result in extensive inter-agent communications. Moreover, agents in a flat MAS must either know the agent identifier number of all agents that they need to interact with, or be provided with location mechanisms such as white and yellow pages services. In our model we use this type of architecture, all the agents can communicate with each other using GPRS network.

3. **A substitution MAS :** is a system in which agents are themselves made up of other agents. In this system, the subsumed agents are completely controlled by the containing agents. The fixed structure of a substitution MAS provides efficiency but restricts the flexibility of the system.

4. **A modular MAS :** is comprised of a number of modules. Each module is typically flat, while inter-module communications are relatively limited..

Characteristics of multiagent systems

What are the fundamental aspects that characterize a MAS and distinguish it from a single-agent system? One can think along the following dimensions:

1. **Agent design :** In multi agent system the design of the hardware and software will change because of the communication between agents. Sometimes these agents are heterogeneous, this will lead to more complex design. Dealing with the environment will change in muli agent systems, the environment will become dynamic because of the multi agent changing.

2. **Perception :** Contrary to single-agent systems, the control in a MAS is typically distributed (decentralized). This means that there is no central process that collects information from each agent and then decides what action each agent should take. The decision making of each agent lies to a large extent within the agent itself. In single-agent systems we typically assume that the agent knows its own actions but not necessarily how the world is affected by its actions. In a MAS, the levels of knowledge of each agent about the current world state can differ substantially.

3. **Communication :** Interaction is often associated with some form of communication. Typically we view communication in a MAS as a two-way process, where all agents can potentially be senders and receivers of messages. Communication can be used in several cases, for instance, for coordination among cooperative agents or for negotiation among self-interested agents.

4. **Control :** Contrary to single-agent systems, the control in a MAS is typically distributed (decentralized). This means that there is no central process that collects information from each agent and then decides what action each agent should take.

5. **Knowledge :** In single-agent systems we typically assume that the agent knows its own actions but not necessarily how the world is affected by its actions. In a MAS, the levels of knowledge of each agent about the current world state can differ

substantially. In a MAS each agent must also consider the knowledge of each other agent in its decision making.

2.2.5 Modeling Transportation domain As Agents

To solve the complex problem of road traffic congestion, researchers using agent technology in this field divide the problem domain into different agents.

Vehicle Agent

This agent can give driver behavior, driving route, driving speed and other information of moving vehicles [5,7,12,19,39,40]. It can receive information from outside across receiving devices, and sometimes it can send information across communication devices. From the speed of the vehicles, this agent can know the kind of the drivers(impulse-type, normal-type and careful type) and driving intention(emergency or non-emergency) [39]. Vehicle agents are equipped with devices to help in collecting traffic data or communicating with other agents. Radio Frequency Identification(RFID) is used in emergency vehicles to send a signal to RFID reader installed beside traffic light to inform it that emergency vehicle need to pass the intersection [5]. This RFID tag is installed in every vehicle in [12] and two RFID readers are installed in every lane of the traffic light. Three emergency vehicles(ambulance, police, fire brigade) in [7] are equipped with GPS navigation system. Drivers has to put their destination on this system before driving. Other agent vehicles are equipped with GPS tracking device which is used to collect real time traffic data [4].

Lane Agent

This agent registers vehicle agent when entering the lane. The traffic light agent can use these information's for adjusting traffic light signal and informing other vehicle agents of congestion roads [39]. This agent uses different technologies to collect traffic data including sensors [5–10], image tracking system [41], and RFID readers [5,12].

Traffic Light Agent

When dealing with different traffic lights as agents, they can communicate and cooperate with each other and with other agents like vehicle agent, lane agent and agent coordinator to achieve optimal performance of traffic lights. In [6] traffic lights agents cooperate with each other through messages. During traffic jam, the traffic light agent will send message to previous traffic light to stop sending vehicles to it (switch to red light) and ask the adjacent traffic light after it to open green signal. This will reduce traffic congestion. In our model we use this criteria in coordination between traffic lights. In emergency cases traffic light agent will switch from a normal state to prioritize state if an emergency vehicle is detected in the radius of traffic light. After the emergency vehicle is passed, the state is returning to normal. If lane occupancy is high, this state is changed to incoming [31].

If congestion occur, many cars will try to pass the intersection at green time. Estimating the average time between vehicles that pass the intersection during green time is used in [12] to detect traffic congestion. If there is congestion, a new configuration of traffic light is accomplished taking into account not affecting other roads. Maximum green time is given to congestion lane to solve the problem. If the problem still exist after that time, the cycle time is changed to the maximum allowed cycle time.

Intersection Agent

The intersection agent is used to optimize traffic light signal after receiving traffic data from monitoring systems. If the problem still exist after optimizing traffic light signal, intersection agent will communicate with neighboring intersections for help [8]. Neural network is used in [2] to decide the amount of neighboring intersections to cooperate in solving congestion.

Area Agent

Area agent is used to reduce the waiting time of vehicles passing through a group of intersections. In [9], area agent is used for a group of intersections with the distance between them is less than 1000 m.

Agent Coordinator

Optimizing single intersection signal may send a huge amount off vehicles to other intersection which will become bottleneck. So coordination between different traffic lights is needed. Agent coordinator is responsible for giving the optimal plan which will make the movement smooth for all the intersections. In [2] agent coordinator will receive the local control action from intersection agent where congestion occur and determine all other intersection agents that may affected by the action taken from specific intersection. Agent coordinator will communicate with affected intersection agents by the action taken by the congestion intersection agent, and give it the influence rate. The influence rate is the percentage change that may happen to traffic flow after changing the plan of traffic light signals of congestion intersection. Finally, the coordinator agent will calculate the global control action of all the network see fig. 2.1.

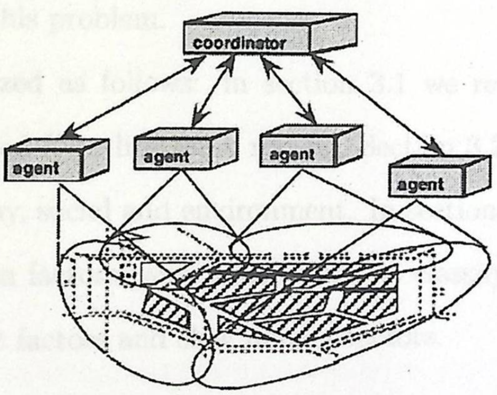

Figure 2.1: Agent Coordinator [2]

Chapter 3

Road Congestion

"'Road congestion is a general phenomenon when capacity of an infrastructure is exceeded"' [42]. In this chapter we try to understand the phenomenon of road congestion. We first review various studies to collect the factors that cause congestion and to examine various solutions introduced in these studies. Then we built a simulation model in Netlogo to deeply study some factors of traffic congestion and to use this model to examine various new solutions for this problem.

This chapter is organized as follows: in section 3.1 we review the factors of road congestion which is collected from literature review. Section 3.2 introduce the impact of road congestion on economy, social and environment. In section 3.3 we present the study we done on road congestion factors using simulation, we classify the studied factors into two categories: fast impact factors and slow impact factors.

3.1 Road Congestion Factors

According to urban mobility report [1], there exist seven sources of road congestion:

1. **Physical Bottleneck:** This occur when traffic flow exceeds capacity. Capacity is defined as the maximum number of vehicles that can travel across specific lane at the same time.

2. **Traffic Incidents:** Any even that disrupt the normal flow of traffic, these include vehicles accidents or breakdowns.

3. **Working Zone:** Construction activities on the roadway. Some working zone prevents the movement while others reduce road capacity.

4. **Weather:** The speed of driving at bad weather decrease, this will slow the movement and make congestion.

5. **Poor Traffic Light Timing**

6. **Special Events:** Like football game or demonstrations.

7. **Traffic Flow:** Traffic flow is dynamic, it is change from time to time. If traffic light system can't adapt to real time changing in traffic flow, congestion will occur. The reasons behind increasing of traffic flow has many factors like the time students leaving schools or employee leaving work.

These factors are related to each other, the occurrence of one factor may cause other factors to occur. Bad weather for example may cause accidents, and high traffic flow may also cause accidents because the vehicles become closer to each other.

3.2 Assessment of Congestion Effects

The effect of congestion can be broken down into three categories according to [42].

1. **Environmental Consequences :** Vehicles operating at low engine loads or idling will produce more carbon monoxide(CO) and hydrocarbon(HC) emissions. This will cause a high pollution for the environment.

2. **Economic Consequences** Estimating the cost of congestion is complex. Time means money. Congestion will increase the time loss for people and cars. This will increase fuel consumption and decrease the productivity of people.

3. **Social and Other Consequences :** Visiting friends at greater distances need a lot of time and money, this will reduce the social contacts. Also, in the tourist sector we would assume changes due to congestion when some destinations at greater distance would be visited less often.

3.3 Studying Road Congestion By Simulations :

It is hard to monitor the impact of congestion factors at various points in traffic network. Simulation is a good facility which can monitor traffic network and addresses the impact of congestion factor on the speed and waiting time of vehicles. We developed a simulation model in Netlogo to study congestion factors.

3.3.1 Netlogo

Netlog is an agent based simulation environment. It uses a simple programming language driven from logo. It give an easy interface which could be changed at run time. This interface includes the use of buttons, switches, sliders and monitors. Simulation time is measured in discrete ticks, and simulation speed can be adjusted with a slider above the display. Netlogo can give outputs in the form of graph and variable monitors. Traffic Grid as seen in fig. 3.1 is an example of sample models built in NetLogo [43].

3.3.2 Simulation Model

To understand the traffic congestion problem we built a simulation model using the Netlogo simulation program see fig. 3.2, this model includes:

1. **Two Intersections:** Each intersection will receive vehicles from east and south according to adjusted traffic flow.
2. **Two Traffic Lights:** These traffic light is installed at each intersection and are adjusted using fixed timing.

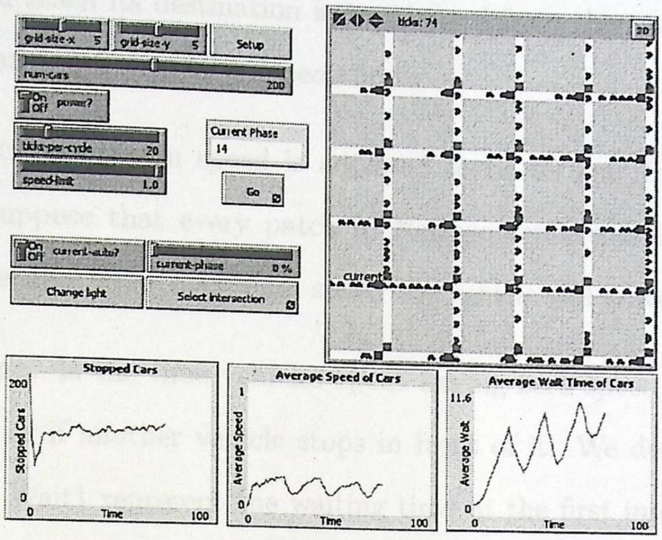

Figure 3.1: Netlogo Traffic Grid Model

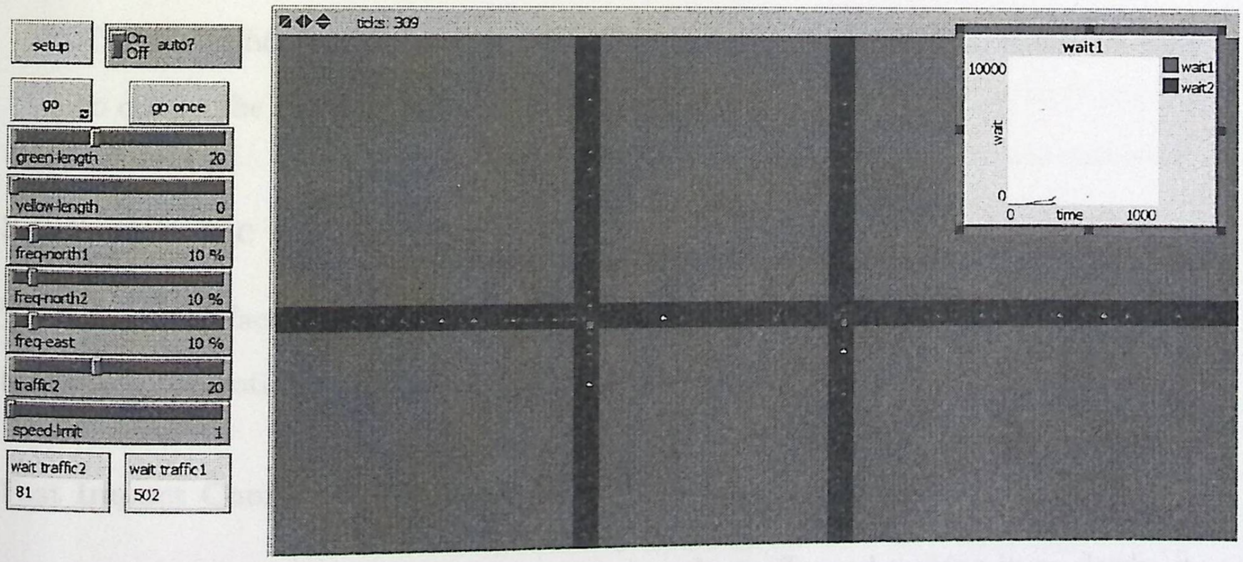

Figure 3.2: Traffic Simulation Model

3. **Vehicles:** Vehicles will come from east and south1 to the first intersection, and the second intersection will receive vehicles from the first intersection (east) and south2. Vehicles which reach its destination is terminated from the system. Every vehicle has a speed ranging from zero to speed limit.

4. **Speed:** Vehicle maximum speed is adjusted to be 50 km/Hr this is mapped to 14 m/s, we suppose that every patch in Netlogo represents 14m and every tick represents 1 second; so at maximum speed the vehicle will travel 1 patch/tick.

5. **Waiting Time:** Is the time vehicles spent having zero speed. Vehicles will stop at a red light or if another vehicle stops in front of it. We define two variable of waiting time. Wait1 represent the waiting time at the first intersection and wait2 is the waiting time at the second intersection.

6. **Traffic Flow:** We adjust traffic flow using sliders. 100% traffic flow means that 1 vehicle will enter the lane every second. We define three traffic flow variables (freq-east, freq-north1, freq-north2) which represents the three destinations where vehicles flow.

7. **Traffic Light Timing:** We used fixed timing for traffic lights. Two sliders are used to choose the suitable timing of every traffic light.

3.3.3 Traffic Congestion Factors

There are many factors that affect traffic situation. According to our simulations we find that traffic congestion factor are divided into two categories :

Fast Impact Congestion Factors

These factors does not need a long time to stop the traffic and making it go slowly, it includes:

1. **Traffic Accidents:** Accidents Impact on road traffic are classified into different categories according to the place where it took place and the time it stops the movements of vehicles on the road. Some accidents stop the movement of vehicles for a little of time (5 minute or 10 minutes). An example of such accidents is when a car hit a person and no injured occur or when a car hit another car and no damaged occur. This kind of accidents has a little impact on traffic network. In fig. 3.3 Other

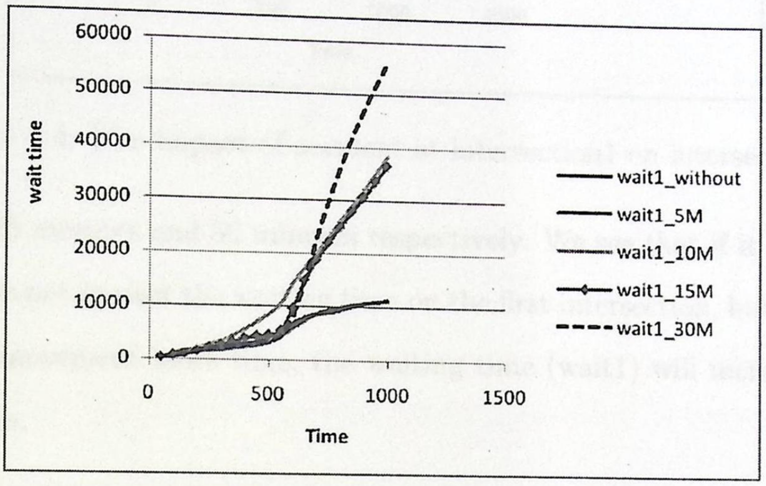

Figure 3.3: Accident Near Intersection1

accidents need the ambulance to come and in some cities the law force drivers not to move cars on the road after the accident took place until the police come. This kind of accidents will stop the movements of vehicles for 15-30 minute or more causing congestion in that area to become very bad. In our experiments we make simulation for 5, 10, 15 and 30 minute accidents. Also we change the place where the accident took place to be between the two traffic lights, in the region of first traffic light and in the region of second traffic light.

the accident took place between the two intersections and it is closer to the first intersection. An accident occurs after tick 500. In this figure wait1_without represents the waiting time at the first intersection without any accident. This waiting time is used as reference to compare with it. Wait1_5M represents the waiting time if an accident occurs and stops the movement for 5 minutes. Wait1_10M,wait1_15M, wait1_30M represents the waiting time after accident stops the movement for 10

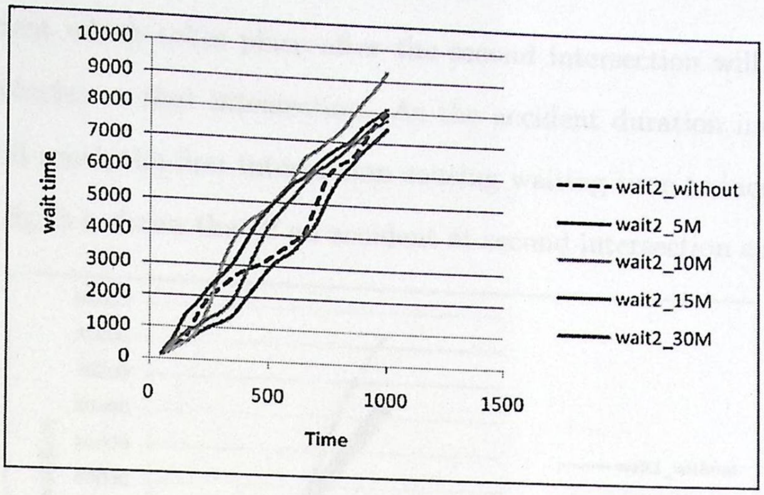

Figure 3.4: The impact of accident at intersection1 on intersection2

minutes, 15 minutes and 30 minutes respectively. We see that if it continue 5 minutes it does not impact the waiting time on the first intersection, but as the accident stops the movement more time, the waiting time (wait1) will increase on the first intersection.

When the accident took place in the region of intersection1, it will stop sending vehicles to the next intersection. This means that the waiting time at the second intersection will not increase see fig. 3.4.

If the accident takes place after the second intersection, waiting time will increase at that intersection as the duration of accident increase see fig. 3.5.

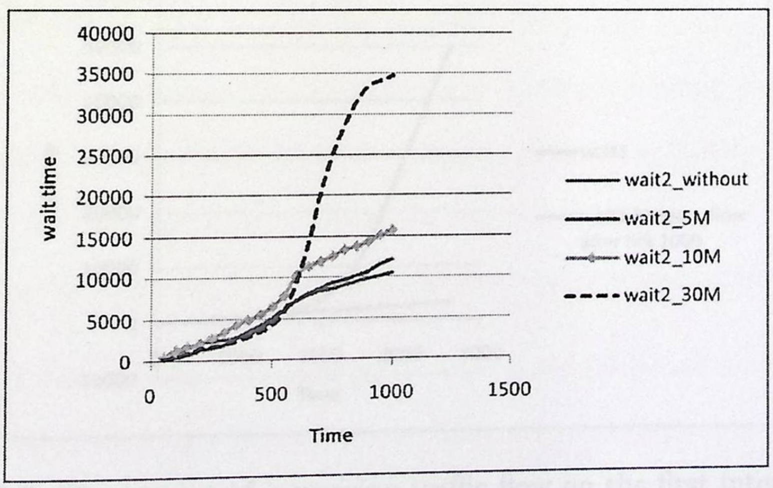

Figure 3.5: Accident after intersection2

This accident which takes place after the second intersection will stop the movement of vehicles at that intersection. As the accident duration increase, stopping vehicles will reach the first intersection causing waiting time to increase at that intersection.fig. 3.6 shows that if an accident at second intersection continue stopping

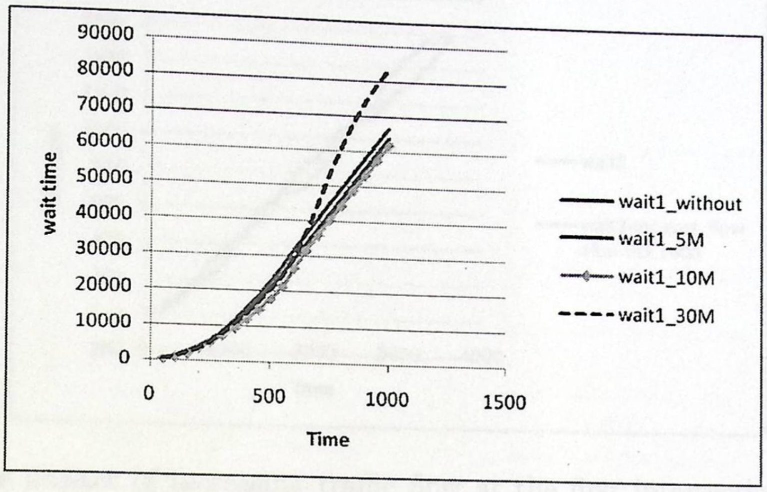

Figure 3.6: The impact of accident after intersection2 on intersection1

movement for 30 minutes, vehicles will reach the first intersection.

2. **Traffic Flow:** Congestion occurs when demand exceeds capacity. So as traffic flow increase, the road network will become more congested. In fixed traffic light timing strategy, traffic light can't deal with the changes occur in traffic flow. Fig. 3.7 Shows

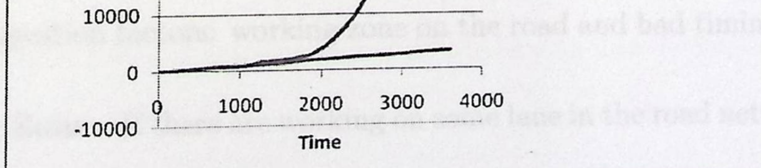

Figure 3.7: The impact of increasing traffic flow on the first intersection

how the waiting time will increase in the first intersection when vehicles flow from the east is increasing. The increase of the flow begins after 1000 ticks.

This increase of traffic flow does not have any impact on the waiting time at the second intersection because in fix timing the first traffic light will keep sending the

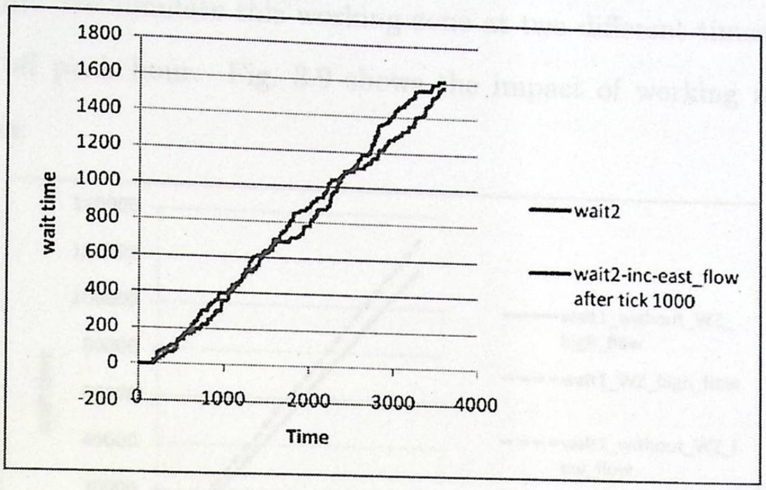

Figure 3.8: The impact of increasing traffic flow at the first intersection to the second intersection

same volume of vehicles to the next traffic light see fig. 3.8.

Slow Impact Congestion Factors

These factors take a longer time to make the traffic congested. An example of such factors is when students leave school. Vehicles will pass slowly in the region where students are walking behind streets to avoid making any accident. This slow driving will begin to build the traffic and as the time pass, the movement will go slowly making the overall network congestion. There are many examples of slow impact congestion factors like bad weather, oil on the road, hawkers and other factors. In our simulation we take two examples of slow impact congestion factors: working zone on the road and bad timing of traffic lights.

1. **Working Zone:** If there are working on some lane in the road network and vehicles can pass across that lane behind the working zone, the movement of vehicles will be slow at that zone causing the traffic to build slowly. The impact of this factor depends on the time of working on the road and the place where the working took

place. If working was done at the peak hour, its impact will be larger on traffic network. We simulate a working zone take place between the two intersections, its length is 42m and vehicles will travel at speeds of 10 km/hr in that zone instead of 50 km/hr. We simulate this working zone at two different times including peak hour and off peak hour. Fig. 3.9 shows the impact of working zone at the first intersection:

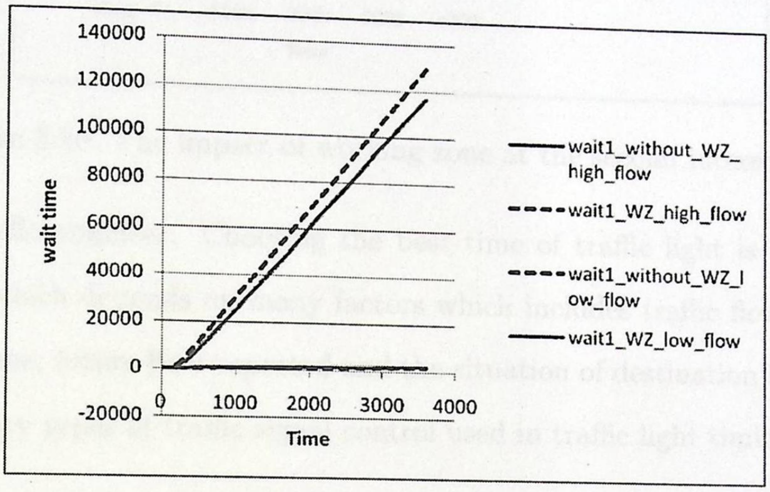

Figure 3.9: The impact of working zone at the first intersection

(a) **peak hour working zone:** In fig. 3.9 we simulate our model for one hour without working zone at high traffic flow(wait1_without_WZ_high_flow) and we use it to compare the change in waiting time after working zone(wait1_WZ_high_flow), we see that the waiting time is increased because at high traffic flow vehicles will build the traffic until it reach the first intersection. But the impact of working zone on the second intersection will be higher see fig. 3.10 because the work is done in the lane going to the second intersection.

(b) **Off-peak hour working zone:** If the traffic flow is low, stopping vehicles will not reach the first intersection so the waiting time will not increase see fig. 3.9 (wait1_WZ_low_flow), the impact of working zone under low flow on the second intersection is higher see fig. 3.10.

2. **Bad Traffic Light Timing:** Traffic light timing is one of the critical problems

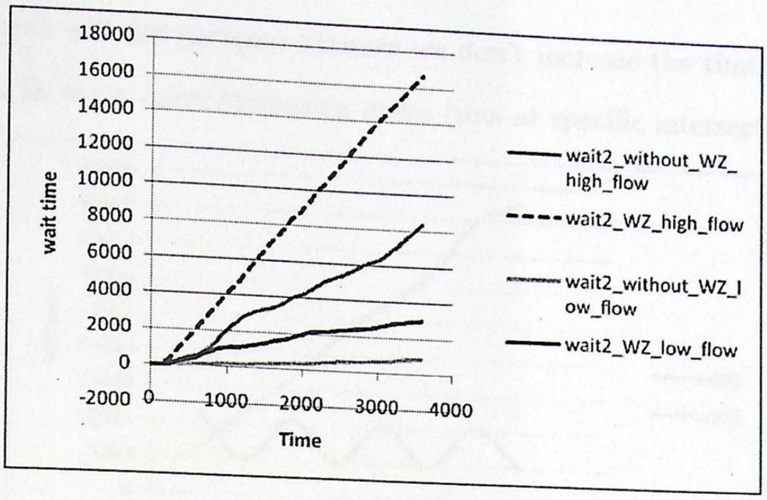

Figure 3.10: The impact of working zone at the second intersection

facing traffic engineer. Choosing the best time of traffic light is an optimization problem which depends on many factors which includes traffic flow, queue length, waiting time, future flow expected and the situation of destination lanes. There are two primary types of traffic signal control used in traffic light timing:

(a) **Fixed Light Timing:** This strategy gives a fixed green time for all the lanes in the traffic. The time needed to complete service all conflicting traffic movements is referred to as the cycle length. The signal timings and cycle lengths may vary by time of day to reflect changes in traffic volumes and patterns. During peak traffic periods for example, cycle lengths may range from 90 - 128 seconds to accommodate heavier volumes. During off peak times of day cycle lengths are reduced as traffic volumes are much lighter and therefore not as much green time is required to effectively service all movements. According to our simulation, pre-timed signals could not be accommodated to changes happened at a traffic light. Traffic flow change from time to time, this makes one signal plane suitable for a specific time to be bad for other times. Increasing the time for specific traffic may not solve the problem fig. 3.11 shows that increasing the green time on traffic one will make the overall waiting time at that traffic to increase. The figure also shows that the adjacent intersection waiting time will not increase because we don't increase the timing of that traffic light. In some cases increasing green time at specific intersection will increase

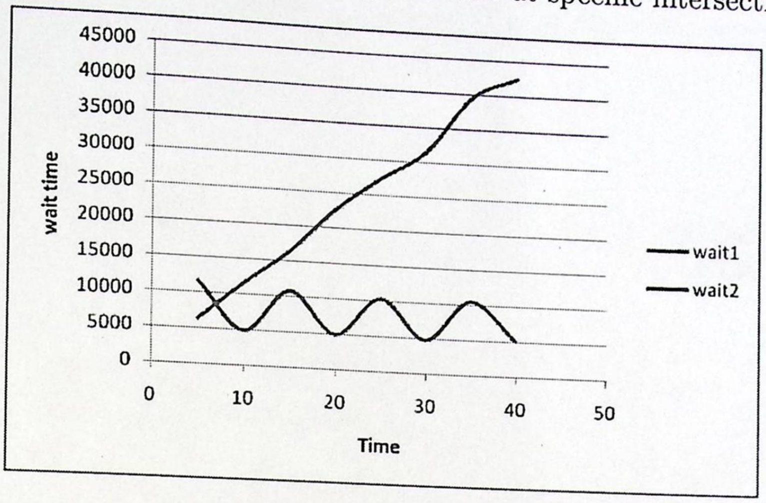

Figure 3.11: The impact of increasing the green timing of first traffic light

the waiting time of previous intersection. Fig. 3.12 shows that increasing the timing of the traffic light at the second intersection will make the vehicles wait more at that intersection, and if the flow is high from the first intersection the waiting vehicles may reach the first intersection and stop the movement of vehicles at that intersection.

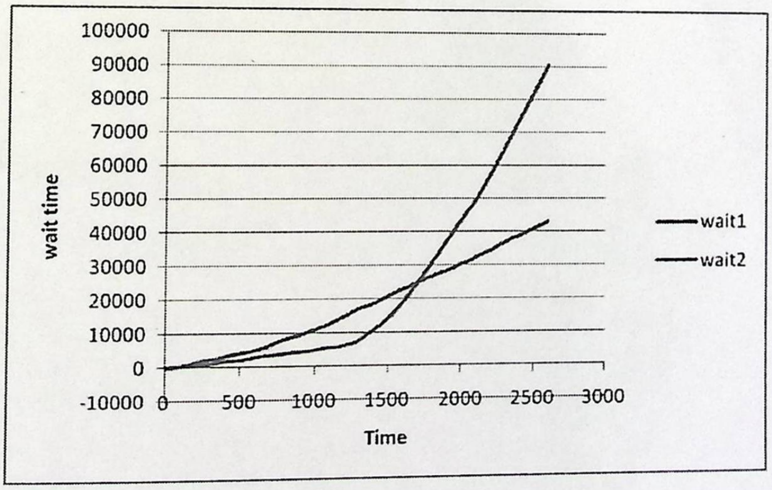

Figure 3.12: The impact of increasing the green timing of second traffic light on the previous intersection

(b) **Actuated Traffic Light Signals:** Actuated traffic light signal is a control strategy in which sensors are installed at waiting queues in the intersection to detect coming vehicles, the traffic light signal is adjusted according to sensor reading. The road with more vehicles will be given more green time. According

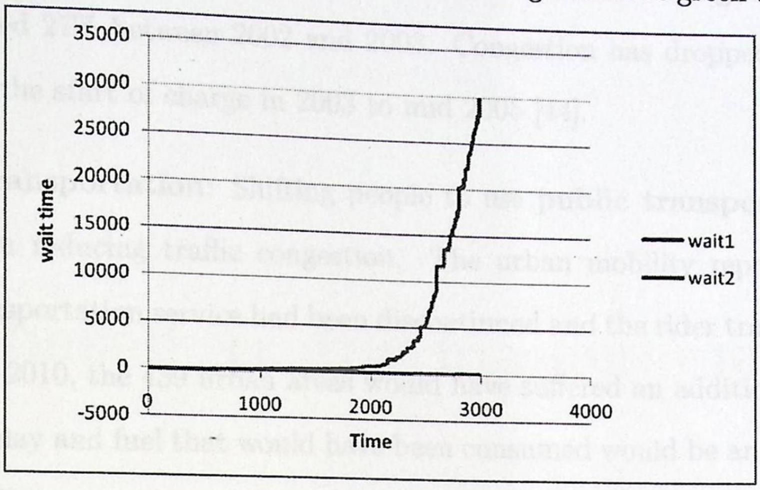

Figure 3.13: Actuated Traffic Signal control

to our simulations, this strategy can give a better result than fixed timing at isolated intersections. But in some cases giving long green signals in specific direction may cause adjacent intersections to become bottlenecks.

As we can see in fig. 3.13 the first traffic light will give along green time to vehicles going to the east, the second traffic light can't give a long time in this direction because south direction has also a high flow. In this case the waiting time at the second intersection will become very high. This strategy can't coordinate between different traffic lights, which may result in a bad result for the overall network.

3.4 Strategies to Deal with Congestion

There are many strategies to deal with road congestion these strategies includes:

1. **Increasing Road Capacity:** This includes adding additional lanes or redesigning bottleneck [1].

2. **Road Charging:** Road charging is another solution for traffic congestion problem [44]. The London department of transport creates the London congestion charg-

ing research program in 1995, this research concludes that a congestion charge would reduce congestion. The number of private cars and trucks coming into central London dropped 27% between 2002 and 2003. Congestion has dropped an average of 30% since the start of charge in 2003 to mid 2005 [44].

3. **Public Transportation:** Shifting people to use **public transportation** service will help in reducing traffic congestion. The urban mobility report says that if public transportation service had been discontinued and the rider traveled in private vehicles in 2010, the 439 urban areas would have suffered an additional 796 million hours of delay and fuel that would have been consumed would be an additional 16.8 billion, 17% increase over current congestion cost [1].

4. **Land Use Planning:** To position facilities closer to people like employment, education and services. This can reduce car trip length and facilitate more walking, cycling and public transport use.

5. **Traffic Management:** The use of intelligent transportation system technology to improve traffic flow and incident management.

Chapter 4

Agent based Traffic management system

Dealing with congestion is a sophisticated problem. Sometimes we can't predict of the occurrence of the congestion and also solving it if it occur is a complex problem. As the number of cars entering road network increase every day, we need an intelligent urban traffic management system. This system needs to collect real time traffic data and take a decision to manage these data to avoid congestion.

In this chapter we'll present an agent approach for congestion management which efficiently manages traffic according to its current condition. Its aim to reduce the time spent in driving. This is achieved by using agent technology. Our approach divide traffic network into agents, each agent is responsible for specific tasks. Some agents collect traffic data and other uses these data to optimize traffic signal or coordinate between traffic signals and drivers. This solution easily to be implemented and it is a low cost solution. There is no need any infrastructures at road network. The presented solution can adapt in real time changing happened in traffic and can manage accidents in easy way. In addition, we have developed an agent based traffic simulator in Netlogo. We compare our model with two other different models.

This chapter is organized as follows: section 4.1 introduce the use of GPS tracking system in our model. Section 4.2 give a brief description of how human think in solving traffic congestion. Section 4.3 give a deep description of using agents in our model and how we use the idea of horn model as an indicator which is used by traffic light agent in optimizing traffic light signal.

4.1 GPS technology

In order to understand traffic condition, we need to collect real time traffic data. Traditional way uses sensors to collect these data. Sensors can't manage the overall network and its installation and maintenance is costly. Using Global Positioning System (GPS) technology become popular in many fields and new cars and mobile phone is equipped with this technology [4,15,16]. In our model we will consider that all the vehicles equipped with GPS tracking device, this device can give the exact position of the vehicles and its speed. From this information we can know the real time traffic data of every lane in the network. Also, traffic light can know the volume of waiting queue and the time vehicles spent waiting for the green light and it can predict the future income to traffic light. The congestion factor of every lane is calculated using GPS tracking devices extracted data. All GPS tracking device information is collected and sent to agents coordinator to manipulate and manage these data.

4.2 Modeling Human Thinking

In the developing countries the use of a horn at streets is common. A traditional way in urban management where traffic is not installed is to put a policeman at each junction to manage the movement of vehicles. When drivers waiting time is increased, they honk to inform the policeman that they wait a long time. The policeman gives more attention to the lane where cars give more horn. As the sound of horn increase in some lane, the policeman gives a green sign to that lane avoiding the noise which caused by waiting vehicles pushing horn. Vehicles drivers push horn more and more as they wait for green sign. If the policeman sees that there is many cars in a specific direction, he will call the adjacent policeman at the adjacent intersection to help him in solving congestion, and also he may call the policeman at the previous intersection to stop sending vehicles to his direction. At specific point the police man may call the police office to send policeman or police vehicle to specific junction to change the route of vehicles to another lane that will stop sending cars to congestion area. This is how human think in solving urban traffic congestion problem. We can model this thinking using agent technology.

4.3 Agent Horn Model

In the previous model there are many agents which include vehicle agent, policeman agent, police office agent. In our model we use agent coordinator, traffic light agent and vehicle agent.

4.3.1 Vehicle Agent

This agent is equipped with GPS tracking device, which is responsible for collecting real time traffic data. The GPS tracking system can give vehicle speed and the exact position of the vehicle while traveling across the road network. This system consists of GPS modules, Wireless communication based on General Packet Radio Service (GPRS) satellite modem see fig. 4.1.

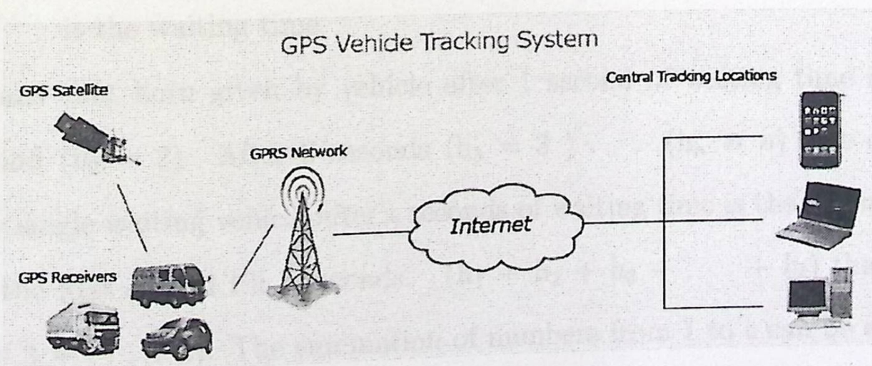

Figure 4.1: GPS Tracking System

The position of the vehicle is updated every 1 second(1 HZ). The recorded location data and speed can be stored within the tracking unit, or it may be transmitted to agent coordinator using cellular (GPRS) radio or satellite modem embedded in the unit. Vehicle agent make demand for green light. This demand is managed by the amount of horn sound (horn indicator) and vehicle count. The vehicle which waits for green light must push the horn. As it waits more, it will push the horn more and more. Also, the receiver of this horn will receive higher sound as the distance of vehicle is closer to it, so horn indicator increase with waiting time and decrease with distance. This horn indicator gives us an indication of the amount of time spent in waiting queue and give aging to a low density lane not to wait too many times.

4.3.2 Vehicle Horn

Horn is an indicator to inform the traffic light that green sign is needed. We use waiting time as the source of this indicator. As the waiting time increase, this indicator is increased. To achieve this we suppose that vehicles produce every second the same amount of horn as its waiting time see eq.4.1

$$h_i = W_i \tag{4.1}$$

Where :

i : represent the steps in second.

W : is the waiting time.

This means that horn given by vehicle after 1 second of waiting time is ($h_1 = 1$). After 2 second ($h_2 = 2$). After 3 seconds ($h_3 = 3$) . . . ($h_n = n$) The overall horn produced by single waiting vehicle after t seconds of waiting time is the summation of all horns from the first second till t seconds. ($h_1 + h_2 + h_3 + \ldots + h_t$) this equivalent to ($1 + 2 + 3 + \ldots + t$). The summation of numbers from 1 to t can be expressed as eq. 4.2

$$H_i = \frac{t(t+1)}{2} \tag{4.2}$$

Where H is the overall horn produce by single vehicle over t waiting time. According to eq. 4.2 if vehicle waits 5 seconds at traffic light its horn amount is (1 + 2 + 3 + 4 + 5) = 15, it is equivalent to (5 * (5 + 1))/2.

4.3.3 Agent Coordinator

In our model agent coordinator receive every second position and speed from vehicles agents using GPRS network and it use map matching to identify to which lane this vehicle belong and it estimate the following :

1. **Congestion Factor(cf):** Every lane has a congestion factor which is the sum of vehicles in the lane divided by lane capacity see eq. 4.3

$$Congestion\ Factor = \frac{Current\ number\ of\ vehicles}{Road\ capacity} \tag{4.3}$$

. This congestion factor is sent to the traffic light agent. If it exceeds a specific threshold, agent coordinator will communicate with vehicle agent to ask it to reroute.

2. **Horn Indicator:** From the speed of vehicles and position, agent coordinator can calculate the time vehicles spent in the waiting queue of every traffic light; this is the time with zero speed. As we said that horn increase with waiting time, it also decrease with distance of vehicles from traffic light because it is a sound. So to calculate the horn indicator we divide the horn amount of every vehicle by its distance from traffic light see eq. 4.4.

$$H_{indicator} = \frac{H_i}{d_i} \tag{4.4}$$

3. **Lane Weight:** This is the weight of the whole lane, which is the summation of

the horn indicator of the first n vehicles in the waiting queue see eq.4.5.

$$Weight_i = \sum_{i=1}^{n} H_{indicator} \tag{4.5}$$

Where

H_i : represent the horn indicator amount of i_th vehicle.

n : number of vehicles in the waiting queue that we estimate its horn.

Agent coordinator will communicate with the traffic light agent to give it the weight and the congestion factor of every lane. This information is updated every 1 second. Agent coordinator will communicate also with vehicle agent to inform it of congestion lane and ask it to reroute. Reroute is decided depending on destination congestion factors, if the destination congestion factor exceeds a specific threshold; agent coordinator will ask vehicle agent to reroute at specific junction. All the communication between agent coordinator and vehicle agent or traffic light agent is achieved using GPRS wireless network.

4.3.4 Traffic Light Agent

The traffic light agent is responsible for optimizing traffic light signal and communicating with other traffic light agents and agents coordinator. The policeman gives the green sign according to what he hears (horn sound) and what he see (vehicle count). In our model, When a traffic lights agent wants to give green time to specific lane it compute the cycle time needed to service all vehicles in all directions, this time is the time needed for a single vehicle to pass the intersection multiply by the number of vehicles in the waiting queues of all lanes of the intersection see eq.4.6

$$C = \sum_{i=1}^{n} N_i * T \tag{4.6}$$

Where

i : represent the lane number.

T : is the time needed to pass the intersection.

N : number of vehicles in all lanes of the intersection.

C : Cycle time.

The green time is given according to eq.4.7

$$G\_i = \frac{cf_i}{\sum_{i=1}^{n} cf_i} * C \tag{4.7}$$

Where

n : is the number of lanes in the intersection.

C : is the cycle time.

cf: is the congestion factor.

After giving a green sign to specific lane, traffic light agent will receive weights of other red light lanes from its agents coordinator. If the weight reaches a specific threshold or the green time is completed, green light is given to that lane see eq.4.8

$$IF\ Weight > T,\ then\ give\ green\ light\ to\ this\ lane. \tag{4.8}$$

.

This optimization strategy gives a dynamic cycle time according to real time traffic data and give each lane the needed time taking into account other lanes not to wait a long time by keeping track of the lane weight which is driven from waiting time.

4.3.5 Agents communication

During travel time, vehicle agent will keep sending its position and speed every second to agent coordinator using GPRS network. Agent coordinator will use map matching to identify to which traffic light agent this vehicle belong and it estimate the congestion factor and lane weight for every lane. This information is sent every second to traffic light agent. If the congestion factor of the lane exceed specific threshold, agent coordinator will send message of the congestion degree to all the vehicles in the lane. Vehicle agent will take a decision to choose another route if it can according to its map. The communication between agent coordinator and vehicle agent is achieved using GPRS network.

Agent coordinator will send congestion factor and lane weight to traffic light agent. Traffic light agent will calculate the cycle time and the green time using congestion factor. Traffic light agent will communicate with previous traffic light asking it to switch to red if the congestion exceed specific threshold. This communication is achieved using GPRS network. If accident took place in destination lane, the traffic light agent will stop sending vehicles to that lane; this will cooperate in solving accident problem. Also traffic light agent can communicate with adjacent traffic light to increase green time to help in reducing congestion. The communication between agents is illustrated in fig. 4.2.

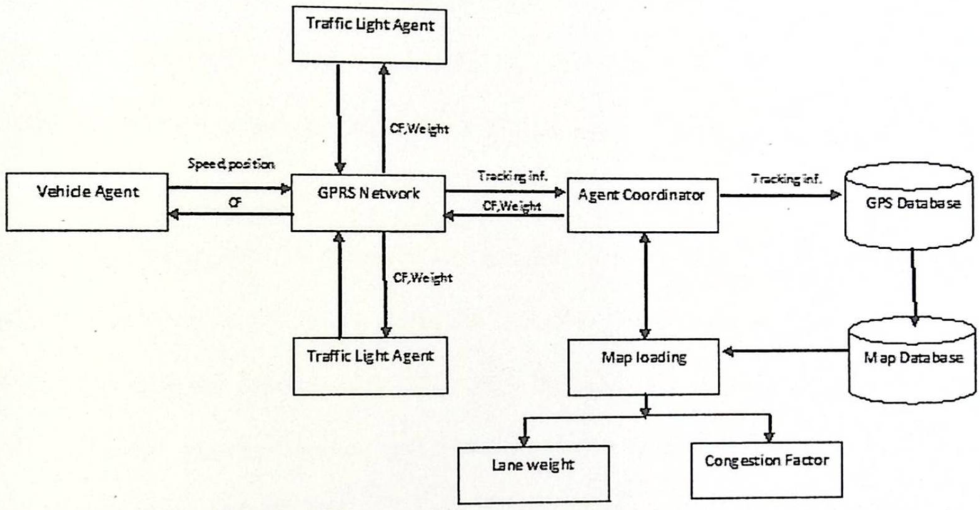

Figure 4.2: Agents Communication

4.3.6 Route Guidance System

Using GPS to choose the best route is common in traffic management system. Some route guidance systems give the best route according to distance and the congestion factor [1], but in our model we will use route guidance for the benefit of the overall system not for specific vehicles. This may be bad for some drivers which force him to go to longer lane, but it is very good to the overall traffic network which will stop sending cars to congested areas. The traffic light Agent will solve the problem of congestion and accidents when it stops sending vehicles to congestion area. In our model agent communicator will use a congestion factor threshold to communicate with vehicles and ask it to reroute. If the congestion factor of the lane exceeds specific threshold, agent coordinator will ask vehicles to reroute see eq.4.9

$$IF\ Congestion\ Factor > R,\ then\ ask\ vehicles\ to\ reroute.. \tag{4.9}$$

Where R : is the congestion factor rerouting threshold.

Chapter 5

Simulations and Results

Agent based simulation can model the traffic road as proactive agents, these agents can communicate with the environment and take its own decision. The traditional way in simulation will model the traffic network as a global graph of queues with add or remove rules [37].

This chapter is organized as follows: in section 5.1 we describes the experimental environment we work on in Netlogo. Section 5.2 describes the two models we used as benchmarking to compare our results with it. Section 5.3 explain the benchmarking metrics which includes the average speed, waiting time and throughput. In section 5.4 we give our experiments and results.

5.1 Experimental Environment

In our research we implement our algorithm on Netlogo simulator. The traffic network consist of two intersections with two traffic light signals, each intersection has two lanes from east and south. Vehicles maximum speed is adjusted to be 50km/hr. Netlogo represent the space as patches and time as ticks. In our model we choose to map 1 patch to represent 14 meters and every 1 tick to represent 1 second. The speed of 50 km/Hr means that the vehicle travel 14 m/s, this is mapped to 1 patch/tick. Vehicles acceleration is chosen to be 3 m/s2, this is mapped to 0.2 patch/tick2. Vehicles are terminated from the system as it reaches its destination fig. 5.1 represents a graphical interface of our model.

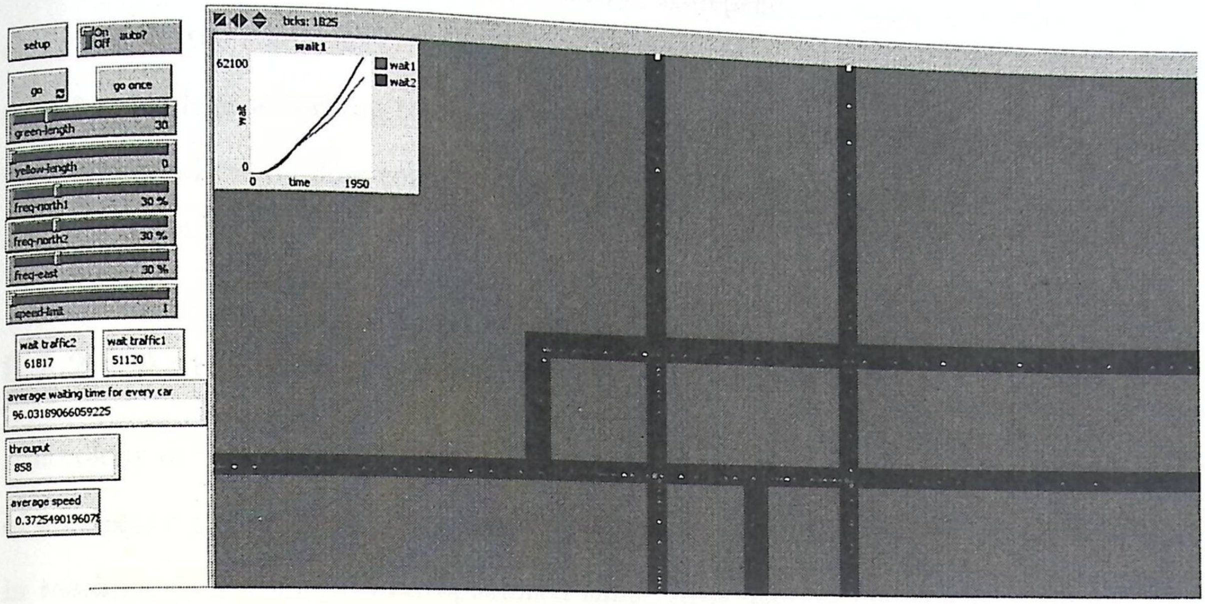

Figure 5.1: Netlogo Traffic Model

Traffic flow and speed limit are adjusted using sliders. 100% traffic flow means that one vehicle will enter the road every second. Our model aims to reduce the average waiting time for the vehicles passing the two intersections. We divided the waiting time into two metrics. Wait1 represents the time spent at the first intersection and wait2 for the second intersection.

5.2 Benchmarking

One of the famous benchmarks for traffic research is the GLIDE system. It is used by many researchers [45–49]. GLIDE is the local name of Sydney Coordinated Adaptive Traffic System (SCATS) which is widely used in more than 70 urban traffic centers in more than 15 countries world wide. [45]. But we can't use this system due to property rights. Other research compare their works with fixed timing traffic light signal strategy [8, 9, 12, 31, 50]. In our research we will compare our results with fixed time traffic signal and ANT Colony Optimization Algorithm.

5.2.1 Fixed Time Traffic Light Timing

This is the model widely used in our country. It depends on assigning specific time for every lane in the traffic according to previous traffic flow monitoring. We implement this model in Netlogo according to the same parameters for our model, Every lane is given a fixed time and traffic flow could be changed using slider. We simulate this model using different traffic flow and different timing of traffic light signals.

5.2.2 Ant Colony Optimization Algorithm

Ant colony optimization algorithm is an optimization algorithm driven from the behavior of ants searching for food. Ants use indirect communication between each other to help in reaching for the food in an optimized time. Ants deposes pheromone in the path to the food, this pheromone concentration in specific path is increased as the number of ants using that path increase. After a short time the shortest path will have the highest amount of pheromone concentration, this will attract all ants to use the shortest path. In [4] pheromone is replaced with the congestion factor to determine the optimum path. In this paper, vehicles are equipped with GPS tracking device, from this device we can know the exact number of vehicles in each lane. The congestion factor is the number of vehicles in a specific lane divided by lane capacity. This congestion factor is used to calculate vehicle speed as seen in eq.5.1

$$Vehicle\ Speed = \frac{Road\ capacity}{Congestion\ factor} \tag{5.1}$$

From vehicle speed we can calculate the expected total travel time, see eq.5.2

$$Total\ Travel\ Time = \frac{Road\ Length}{Agent\ Speed} \tag{5.2}$$

The algorithm chooses the best route according to the optimal total travel time.

5.3 Benchmarking Metrics

Many evaluation metrics have been used in transportation research includes:

5.3.1 Average Speed

It is the mean speed of all vehicles traveling on the network during certain period. It is used in [12, 15, 19],it gives an indication of the movement of vehicles across the network, it is better to approach the maximum speed. In our simulation we compute the mean speed after the end of each simulation.

5.3.2 Waiting Time

It is the time vehicles spent without moving (speed = 0), this time is the sum of all stopping intervals at a traffic light or across the road. Sometimes it is indicated as the total travel time which is increased as the waiting time increase as in [31], or as average delay as in [9,12,50]. In our simulations we will divide the waiting time as wait1 and wait2 which describes the waiting time spent at the first intersection and second intersection. We also use average waiting time metric which is the average time spent by every vehicle this is calculated by dividing the overall waiting time by the vehicle counts see eq.5.3.

$$Average\ waiting\ time\ for\ every\ vehicle = \frac{Waiting\ time}{Vehicles\ count} \tag{5.3}$$

5.3.3 Throughput

The aim of every traffic management system is to increase the throughput of the overall network. Sometimes we can increase the throughput for single intersection, but this may make other intersection bottleneck. The challenge is to increase the throughput of the overall network which means to increase the number of vehicles reaching its destination in specific periods. In our simulation we compute the total number of vehicles reaching its destination and we divide it by the overall vehicles count in the network this gives us the throughput of the system during a specific period as indicated in eq.5.4

$$Throughput = \frac{Terminated\ vehicles}{Vehicles\ count} \tag{5.4}$$

5.4 experiments and results

In our model we try to explore the behavior of our algorithm under different conditions. The varying conditions that we concentrate on are traffic flow and accidents which are classified in our background as a fast congestion factor. Traffic flow varies from time to time and in our model vehicles are coming from east, south1 and south2. We examine two kinds of traffic flow (high and low). In high traffic flow we generate 1000 vehicles for each lane per hour, while in low traffic flow we generate 370 vehicles per hour for every lane, this traffic flow data is taken from the manual count took place in bab ezqaq in Bethlehem. This manual count is done by Dr. Musab shaheen in project funded by USAID. As vehicles come from three different places (east,south1,south2), each place has two probability of traffic flow (high or low). We need three different combination of traffic flow, this will need ($2^3 = 8$) of experiments to complete it. The same experiments under the same conditions are done for fixed traffic timing and Ant colony optimization model. We simulate these two models to compare our results with it. Simulation is repeated 5 times in each experiment and the average value is taken as the output. **Horn Algorithm** will use weight threshold for the traffic light to switch when specific lane reach that threshold. Another threshold is the **routing threshold**, when the destination lane congestion factor reaches that threshold traffic light is switched to red light. For vehicles, lane agent will contact vehicles and ask it to reroute. If we suppose that vehicle length is 4m and the safe distance between vehicle is 2 second which is equivalent to 6 vehicles length(24m), the remaining distance of patch if a vehicle stop at it is 10m because the patch length is 14m. To complete the safe distance we need another free patch. This means that if one patch has vehicle the next patch must be free, so if 50% of patches is full, this means that the road is full. So We choose the routing threshold to be 50%.

To examine our solution, we need to make simulation under different traffic flow. We choose two kinds of traffic flow(high and low). In some experiments, traffic light will receive high traffic flow(h) or low traffic flow(L) from the two sides. In other experiments, traffic light will receive unbalance traffic flow from the two sides. This three types of experiments will give an indication of the performance of our algorithm under various traffic flow. We also examine if our model will solve the problem of accidents, this is done under high traffic flow situation.

Traffic flow is come from east and south to the first intersection and the second intersection will receive vehicles from the first intersection and south2. The three lanes of traffic flow(east,south1,south2) is expressed in our experiments as letters. We use the letters (hhh) to donate that the traffic flow is high from the three flow lanes. If the first lane receive high traffic flow from east and low traffic flow from south1 and the second intersection receive low traffic flow from south2, this is expressed as hLL in our experiments.

5.4.1 Experiment.1

In this experiment traffic flow is high from all lanes. This means that the first intersection will receive 1000 vehicles per hour from east and south1 and the second intersection will receive vehicles coming from the first intersection (east) and 1000 vehicle per hour from south2. Fixed timing used 40 second cycle time for each intersection, this cycle time is divided between the two lanes(20 second for each one). We simulate this situation for one hour and we see that our algorithm (agent horn algorithm) give least waiting time for the first and second intersection as we can see in fig.5.2 and fig.5.3 Our results show that our algorithm will speed-up the system 16% more than ANT model and 27% more than fixed timing. The throughput is increased 7% than ANT model and 19% more than a fixed timing model. The average waiting time is reduced 64 second for every vehicle than the waiting time of ANT model and 77 than fixed timing model see table.5.1.

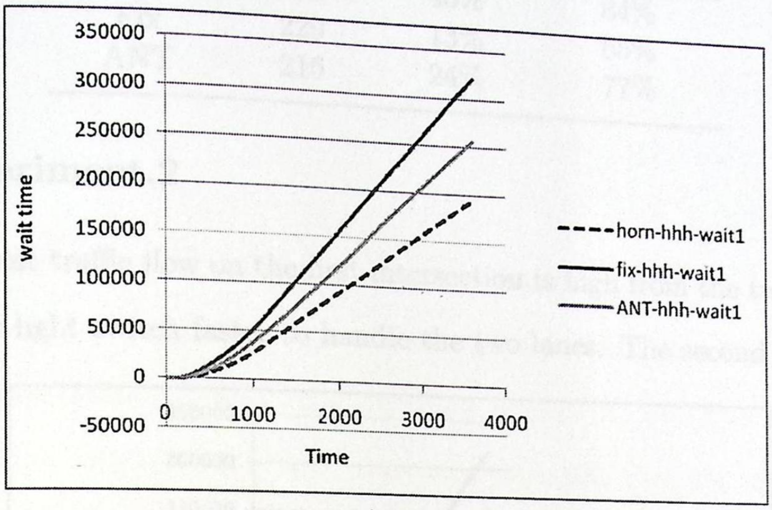

Figure 5.2: Traffic simulation of the three models for the first intersection under congestion from east,south1,south2

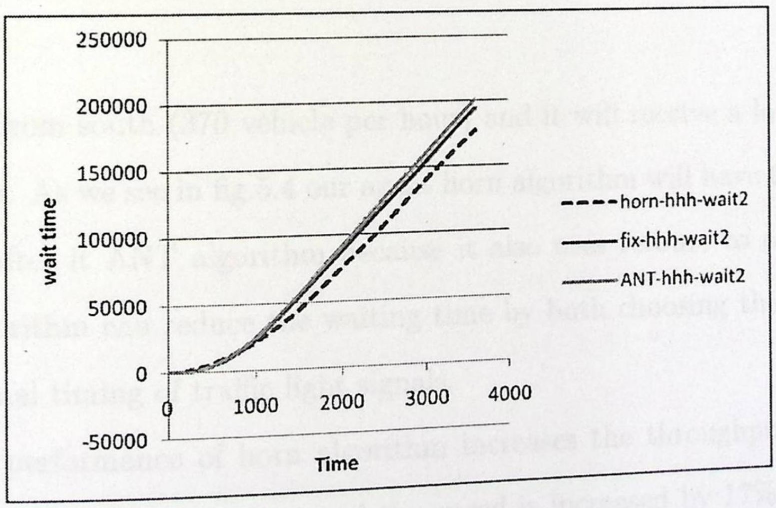

Figure 5.3: Traffic simulation of the three models for the second intersection under congestion from east,south1,south2

Table 5.1: Results of the First experiment

Algorithm	Av-Wait	Av-Speed	Throughput
Horn	152	40%	84%
Fix	229	13%	65%
ANT	216	24%	77%

5.4.2 Experiment.2

In this experiment traffic flow on the first intersection is high from the two lanes,this will make the traffic light switch faster to handle the two lanes. The second intersection has

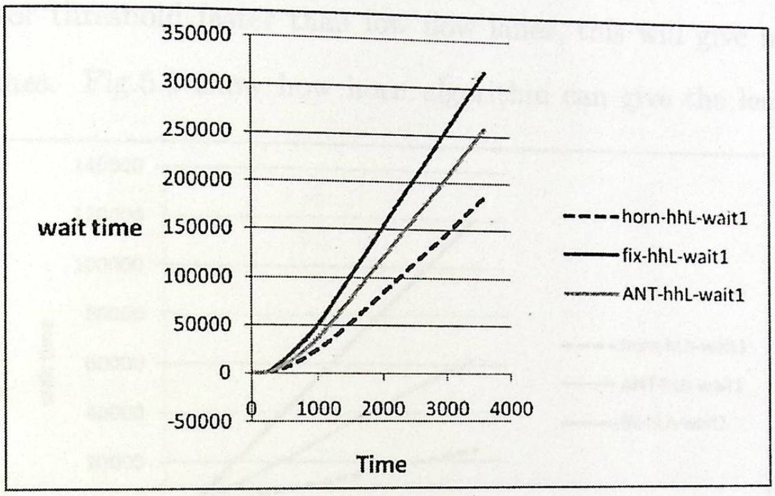

Figure 5.4: Traffic simulation of the first intersection under congestion from east and south

low traffic flow from south (370 vehicle per hour) and it will receive a low flow from the first intersection. As we see in fig.5.4 our agent horn algorithm will have the least waiting time, Coming after it ANT algorithm because it also uses reroute to solve congestion. Agent horn algorithm can reduce the waiting time by both choosing the best route and giving the optimal timing of traffic light signals.

The overall performance of horn algorithm increases the throughput of the overall network by 6% than ANT algorithm and the speed is increased by 17% than ANT and 32% than fixed timing. Table.5.2 show the detail results of this experiment.

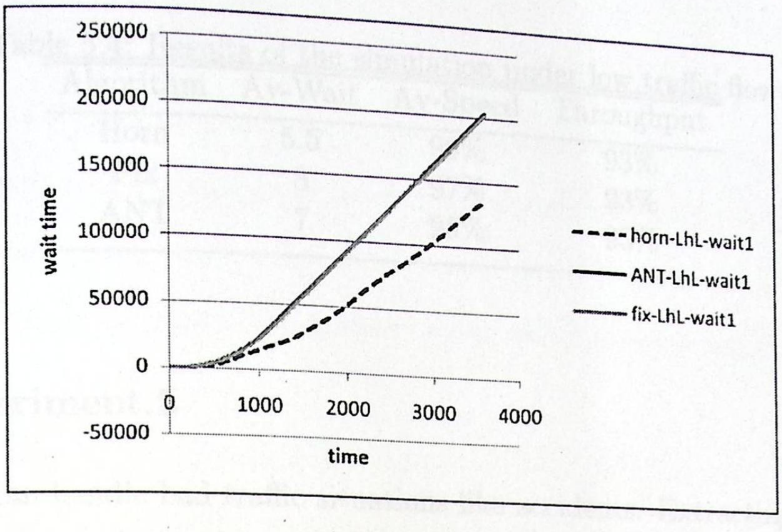

Figure 5.6: ANT algorithm under no reroute choice

Table 5.3: Results of the Third experiment

Algorithm	Av-Wait	Av-Speed	Throughput
Horn	108	49%	85%
Fix	161	12%	62%
ANT	135	29%	79%

5.4.4 Experiment.4

If the traffic flow is low, a reroute is not needed and what we need is a fast traffic light switching. Our algorithm can estimate the needed time for every lane and optimize traffic light according this time. Fixed timing will give more time than needed in low flow, so our algorithm can give better results than a fixed timing algorithm. Fig.5.7 shows that horn algorithm will give the least waiting time table.5.4.

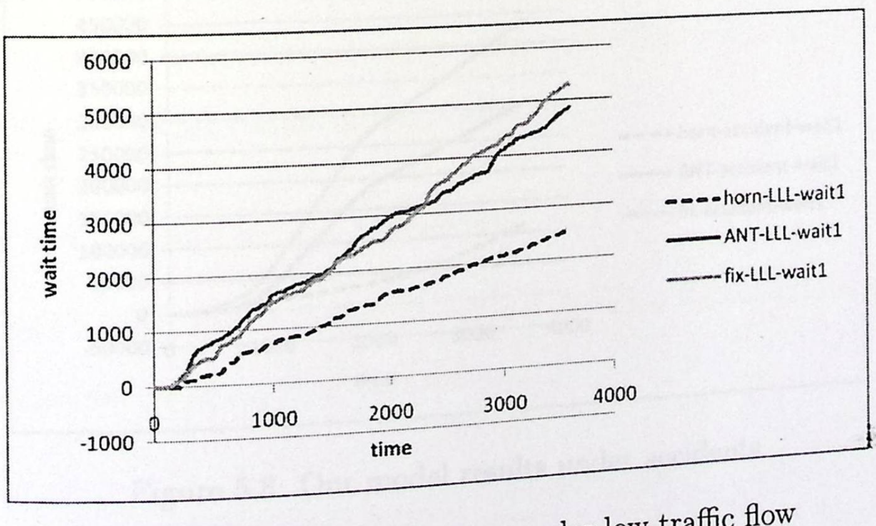

Figure 5.7: Traffic simulation under low traffic flow

5.4.6 Experiment.6

Choosing the lane weight threshold for traffic light signal to switch on it is another optimization problem which needs more studies. In our algorithm, if red light lane weight reaches specific threshold before other lane completed their given green time, switching to green signal must take place. We examine many thresholds for weight switching.

Fixed weight threshold:

Using fixed threshold for weight switching may be good in specific traffic flow and bad for other traffic flow. As we can see in table. 5.5, when traffic flow is high at one lane

Table 5.5: Fixed weight threshold

Threshold	Av-Wait-Lhh	Av-Wait-LLL	Av-Wait-hhh
50	144	4.9	198
100	151	5.8	184
150	153	6.3	181
200	142	6.4	193
250	163	5.7	185
300	138	7	194
350	162	6.5	194
400	105	7.4	185
450	117	5.8	188
500	147	6	190

and low at the other lane, the threshold of 400 gives the best result of waiting time. This threshold (400) is bad in another situation when traffic flow is low at the two lanes, a threshold of 50 gives better results in this situation.

Congestion factor based weight threshold:

In this threshold we take the cycle time of traffic light signal for the two lanes and divide it by a congestion factor of red light lane see eq. 5.5.

$$Weight\ threshold = \frac{Cycle\ time}{Congestion\ factor} \tag{5.5}$$

As the congestion factor increase, the weight threshold will decrease. This will make congestion lanes reach weight threshold faster than non congestion lanes. This threshold gives better results than fixed threshold.

As we can see in table. 5.6, depending on cycle time and congestion factor can reduce the average waiting time for vehicles. If the traffic flow is low, fixed threshold gives better results.

Table 5.6: Congestion factor based weight threshold

Threshold	Av-Wait-Lhh	Av-Wait-LLL	Av-Wait-hhh
congestion threshold	81	6.4	168
Fixed threshold	105	4.9	181

Green time based threshold:

The weight for single vehicle after t of waiting time is $\frac{t(t+1)}{2}$. If we suppose that single vehicle must wait until the green time of another lane is completed, so the weight of this single vehicle is $\frac{G_{time}(G_{time}+1)}{2}$.

We use this weight as a threshold. If one vehicle is waiting, it will not reach this threshold until other green lane signal is completed. If more than one vehicle is waiting, this threshold will be reached before the green time of another lane is completed. This green time threshold will give better results than the previous two thresholds as we can see in table. 5.7.

Table 5.7: Green time based weight threshold

Threshold	Av-Wait-Lhh	Av-Wait-LLL	Av-Wait-hhh
Green time threshold	76	6.5	157
congestion threshold	81	6.4	168
Fixed threshold	105	4.9	181

5.4.7 Experiment.7

In our algorithm lane agent receive the waiting time from the first (N) vehicles of the waiting queue to estimate the horn indicator. In this experiment we want to choose the best number of vehicles to estimate their horn indicator. We examine the waiting time under various traffic flows and with changing the number of vehicles that we estimate their horn indicator. The best results are given when we take 6 vehicles and estimate their weight see table. 5.8.

Table 5.8: The number of vehicles in waiting queue to estimate their horn indicator

Vehicles-count	Wait-hhh	Wait-LLL	Wait-Lhh	wait-hhL
1	211478	18321	127738	136534
2	206450	14788	119320	136274
3	208902	13855	113538	134280
4	207664	**13317**	110839	135510
5	202995	14450	107521	**133622**
6	**194926**	13431	**105827**	136109
7	214498	13806	121152	134864

Chapter 6

Conclusion and Future work

6.1 Conclusion :

Many solutions for the problem of road traffic congestion are adopting agents in optimizing traffic network and reducing the average time vehicle spent in the network. However, a few studies give a global view of agents and how these agents can communicate and cooperate in solving the problem of congestion. In this these, we present a solution for road congestion which depend on both optimizing traffic light signal and communication between different traffic lights and vehicles to cooperate in solving the problem. In our solution, we optimize traffic light signal depending on the number of waiting vehicles and the waiting time these vehicles spent in the waiting queue. We present a new model called horn model, which use the idea of horn as an indicator that vehicles agent used to inform the traffic light agent that it need a green signal. In this way traffic light agent will cooperate with vehicles agent to decide to which lane to give green signal and how long this signal should be.

Our results show that if we combine the number of waiting vehicles and the waiting time in optimizing traffic light signal we will get a better results than depending on the number of queue vehicles only. In some cases, traffic light can't solve the problem separately. It may need to cooperate with another traffic light or inform the drivers to reroute. From table.6.1 it is clearly shown that the new horn algorithm is more optimal than fixed timing and ant algorithm in all cases, and when traffic flow increase, the power of horn algorithm rises to handle the congestion problem. The speedup varies due to traffic flow. As the amount of vehicles increase, the system becomes more congested and the speed is reduced. It is clear in table.6.1 that the new system does not only beat the old one when comparing the average waiting time, but also the throughput of the new system is better in all cases.

Table 6.1: Results of all experiments

Algorithm	Av-Wait	Av-Speed	Throughput
Horn-hhh	152	40%	84%
Fix-hhh	229	13%	65%
ANT-hhh	216	24%	77%
Horn-hhL	100	45%	85%
Fix-hhL	160	13%	63%
ANT-hhL	135	28%	79%
Horn-hLh	108	49%	85%
Fix-hLh	161	12%	62%
ANT-hLh	135	29%	79%
Horn-hLL	20	55%	87%
Fix-hLL	76	13%	64%
ANT-hLL	39	26%	79%
Horn-Lhh	156	52%	87%
Fix-Lhh	259	36%	84%
ANT-Lhh	257	36%	84%
Horn-LhL	78	52%	89%
Fix-LhL	160	48%	88%
ANT-LhL	162	51%	87%
Horn-LLh	83	63%	89%
Fix-LLh	155	46%	87%
ANT-LLh	163	43%	88%
Horn-LLL	6.8	96%	93%
Fix-LLL	8	97%	93%
ANT-LLL	7	95%	93%

Our study show that depending on optimizing traffic light signal only at very high traffic flow will not solve the problem. We need to stop sending vehicles to congestion area by informing vehicles of congestion degree, and cooperate with different traffic lights in solving the problem.

6.2 Future Work :

We introduce a new model called horn model and we apply it on two intersections. For future work, this model has to be simulated onto larger network to check its scalability. We need to add another four intersections to check the communication and coordination between traffic light agents. In this case reroute will become more complex, other factors has to be taken into account like traffic light status and destination congestion factor. Coordination between traffic lights agents will become more complex because switching to red if destination is congestion may cause previous traffic light to become bottleneck. This model has to be evaluated using GLIDE benchmark because it is the most popular benchmark in this field. Our model deals with one alternative path, for future work this model has to be evaluated using full map with many alternative paths and the complication of using the best path has to be checked. In this model traffic light agent use weight threshold for switching from red to green light, this threshold could be chosen using machine learning techniques. Our model focus on two factors of road congestion which are traffic flow and road accidents, other factors has to be checked in future work like working zone and bad weather.

Bibliography

[1] D. Schrank and T. Lomax, "The 2011 urban mobility report," *Texas Transportation Institute*, 2011.

[2] K. Almejalli, K. Dahal, and A. Hossain, "An intelligent multi-agent approach for road traffic management systems," *18th IEEE International Conference on Control Applications*, pp. 825–830, 2009.

[3] UNFPA, "Technical report : state of world population 2007 : unleashing the potential of urban growth," pp. 1–99, 2007.

[4] S. Nahar and F. Hashim, "Modelling and analysis of an efficient traffic network using ant colony optimization algorithm," *Third International Conference on Computational intelligence and communication system and Networks*, 2011.

[5] A. Salama, B. Saleh, and M. eassa, "Intelligent cross road management system(icrtms)," *Second International Conference on computer technology and Development*, 2010.

[6] C. Cai and Z. Yang, "Study on urban traffic management based on multi-agent system," *Six International Conference on Machine Learning and Cybernetric*, pp. 19–22, 2007.

[7] Y. Saeed, M. Khan, K. Ahmed, and A. Mubashar, "A multi-agent based autonomous traffic lights control system using fuzzy control," *international journal of scientific and engineering*, 2011.

[8] W. Qianjiao and L. Rong, "An intelligent traffic control model based on intersection agent," *IEEE*, 2009.

[9] F. Chen and H. Pang, "Study of multi-agent area coordination control for urban traffic," *seven World Congress on Intelligent Control and Automation*, pp. 4046–4050, 2008.

[10] X. Chen, Z. Yang, and H. Wang, "A multi-agent urban traffic control system co-operated with dynamic route guidance," *Fifth International Conference on Machine Learning and Cybernetric*, pp. 330–335, 2006.

[11] L. Zang, L. Jia, and Y. Luo, "An intelligent control method for urban traffic signal based on fuzzy neural network," *Proceeding of the 6th World Congress on Intelligent Control and Automation*, pp. 3430–3434, 2006.

[12] A. Ibanez, J. Castillo, R. Buenrostro, A. Marti, and A. Munoz, "A policy-based multi-agent management approach for intelligent traffic-light control," *IEEE Intelligent Vehicles Symposium*, pp. 694–699, 2010.

[13] P. Manikonda, A. Kumar, and S. Sasank, "Intelligent traffic management system," *IEEE Conference on Sustainable Utilization and Development Engineering and Technology(STUDENT)*, pp. 119–122, 2011.

[14] N. Chadil, A. Russameesawang, and P. Keeratiwintakorn, "Real time tracking management system using gps, gprs and google earth," *Proceeding of ECTI-CON*, pp. 393–396, 2008.

[15] Y. Ho, Y. Wu, M. Chang, T. Wen, and Y. Sun, "Gps data based urban guidance," *International Conference on Advances in social Networks analysis and Mining*, pp. 703–708, 2011.

[16] A. Lonita, A. Zafiu, and V. Lonescu, "A quick solution for traffic control," *Second International Conference on computer Research and Development*, pp. 859–862, 2010.

[17] D. Ren and A. Xu, "Research on intelligent road pricing system based on gps/gis integrated technology," *Liaoning Technical University of China.*

[18] R. Wunderlich, C. Liu, I. Elhanany, and T. Urbanik, "A novel signal scheduling algorithm with quality-of-service provisioning for an isolated intersection," *IEEE Transaction on Intelligent Transportation Systems*, vol. 9, no. 3, pp. 536–547, 2008.

[19] G. Amaout, M. Khasawneh, J. Zhang, and S. Bowling, "An intellidrive application for reducing traffic congestion using agent-based approach," *IEEE System and Information Engineering Design Symposium*, pp. 221–224, 2010.

[20] C. Dobre, A. Ichimescu, and V. Cristea, "Adaptive traffic optimization," *IEEE 6th International Conference on Complex Intelligent and Software Intensive System*, pp. 761–766, 2012.

[21] A. Lakas and M. Chaqfeh, "A novel method for reducing road traffic congestion using vehicular communication," *ACM*, pp. 16–20, 2010.

[22] S. Chavan, R. Deshpande, and J. Rana, "Design of intelligent traffic light controller using embedded system," *IEEE Second International Conference on Emerging Trends in Engineering and Technology, ICETET-09*, pp. 1086–1091, 2009.

[23] Z. Huang, C. Li, and Z. Zhang, "Traffic signal based on genetic network algorithm," *IEEE*, pp. 31–34, 2010.

[24] C. Gershen, "Self organizing traffic lights," *Complex System Publication, Inc*, pp. 29–53, 2005.

[25] P. Jain and M. Sethi, "Fuzzy based real time traffic signal controller to optimize congestion delays," *IEEE Second International Conference on Advanced Computing and Communication Technology*, pp. 204–207, 2012.

[26] H. Wei, W. Yong, M. Xuanqin, and W. Yan, "A cooperative fuzzy control method for traffic light," *IEEE intelligent Transportation Systems Conference Proceedings*, pp. 185–188, 2001.

[27] L. Feng, D. Yingying, and Z. Nianbo, "A practical route guidance approach based on historical and real-time traffic effects," *Hi-Tech Research and Development Program of China*, 2007.

[28] A. Asar, M. Ullah, J. Ahmed, and R. Hasnain, "Traffic responsive signal timing plan generation based on neural network," *4th IEEE Conference on Automation Science and Engineering*, pp. 833–838, 2008.

[29] S. Tantawy and B. Abdulhai, "An agent based learning toward decentralized and coordinated traffic signal control," *IEEE Annual Conference on Intelligent Transportation System*, pp. 665–670, 2010.

[30] M. Khanjary and S. Hashemi, "Route guidance systems: Review and classification," *EATIS'12 Conference Proceeding*, pp. 269–275, 2012.

[31] H. Quanye, W. Xiaoming, and D. Jianwu, "A cooperative multi-agent system in traffic control," *twenty seven Chinese Control Conference*, pp. 577–580, 2008.

[32] S. Russell and P. Norvig, *Artificial Intelligence: A Modern Approach.* Prentice Hall, third edition ed., 1995.

[33] R. Jennings and M. Wooldridge, "Software agents iee review," pp. 17–20, 1996.

[34] H. Nwana and D. Ndumu, "Research and development challenges for agent based system," *IEE Proc. Softw*, vol. 144, no. 1, 1997.

[35] C. Bo and H. Cheng, "A review of the application of agent technology in traffic and transportation systems," *IEEE Intelligent Transportation System*, vol. 11, pp. 485–497, 2010.

[36] N. Jennings, K. Sycara, and M. Wooldridge, "A roadmap of agent research and development," *Kluwer Academic Publishers*, pp. 275–306, 1998.

[37] I. Michal, M. Jakob, P. Rer, R. Martin, and S. David, "Agent technology and its applications," *ACM*, 2010.

[38] H. Nwana, "Software agent: An overview," *Knowledge Engineering Review*, 1996.

[39] L. Zhou and K. Zhao, "The design of agent-based intelligent traffic visualized simulation system," *International Conference on Electrical and Control Engineering*, pp. 3066–3069, 2010.

[40] F. Wang, "Agent-based control for networked traffic management systems," *IEEE*, pp. 92–96, 2005.

[41] S. Tseng and K. Song, "Real time image tracking for traffic monitoring," *IEEE Fifth International Conference on Intelligent Transportation Systems*, 2002.

[42] E. R. Center, "Report of the hundred and tenth round table on transport economic," *European Conference of Ministers of Transport*, 1998.

[43] U. Wilensky, "Netlogo http://ccl.northwestern.edu/netlogo/.," *Center for Connected Learning and Computer Based Modeling, Northwestern University*, 1999.

[44] J. Leape, "The london congestion charge," *Journal of Economic Perspectives*, vol. 20, no. 4, pp. 157–176, 2006.

[45] M. Choy and J. Jrohkaew, "Cooperative hybrid agent architecture for real time traffic signal control," *IEEE TRANSACTIONS ON SYSTEMS MAN AND CYBERNETICS PART A SYSTEMS AND HUMANS*, vol. 33, no. 5, pp. 597–607, 2003.

[46] D. Srinivasan, M. Choy, and R. Cheu, "Neural networks for real-time traffic signal control," *IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS*, vol. 7, no. 3, pp. 261–272, 2006.

[47] D. Srinivasan and M. Choy, "Neural networks for continuous online learning and control," *IEEE TRANSACTIONS ON NEURAL NETWORKS*, vol. 17, no. 6, pp. 1511–1530, 2006.

[48] C. CHEE, "Distributed geometric fuzzy multiagent urban traffic signal control," *IEEE TRANSACTIONS ON NEURAL NETWORKS*, vol. 11, no. 3, pp. 714–727, 2010.

[49] B. Gokulan, "Cooperative, hybrid multi-agent systems for distributed, real-time traffic signal control," *NATIONAL UNIVERSITY OF SINGAPORE*, 2005.

[50] V. Hirankitti and J. Jrohkaew, "An agent approach for intelligent traffic-light control," *IEEE First Asian International Conference on Modeling & Simulaion*, 2007.