A Multiagent System for Optimizing Urban Traffic

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Abstract

For the purposes of managing an urban traffic system, a hierarchical multiagent system that consists of several locally operating agents each representing an intersection of a traffic system is proposed. Local Traffic Agents (LTAs) are concerned with the optimal performance of their assigned intersection; however, the resulting traffic light patterns may result in the failure of the system when examined at a global level. Therefore, supervision is required and achieved with the use of a Coordinator Traffic Agent (CTA). A CTA provides a means by which the optimal local light pattern can be compared against the global concerns. The pattern can then be slightly modified to accommodate the global environment, while maintaining the local concerns of the intersection.

Functionality of the proposed system is examined using two traffic scenarios: traffic accident and morning rush hour. For both scenarios, the proposed multiagent system efficiently managed the gradual congestion of the traffic. As one roadway becomes more congested, the duration of the traffic lights of neighboring intersections leading towards the congested area are reduced by the CTA. If this reduction to the incoming traffic is insufficient, and the roadway continues to reach a congested state, then the LTA attempts to divert traffic using alternative directions.

1 Introduction

The 20^{th} century witnessed the worldwide adoption of the automobile as a primary mode of transportation. Coupled with an expanding population, present-day traffic networks are unable to efficiently handle the daily movements of traffic through urban areas. Improvements to road networks are often confined by the boundaries of existing structures. Therefore, the primary focus should be to improve traffic flow without changing the layout or structure of the existing roadways.

Any solution must handle three basic criteria, including: dynamically changing traffic patterns, occurrence of unpredictable events, and a non-finite based traffic environment [2]. Multiagent systems provide possible solutions to the traffic problem, while meeting all necessary criteria. Agents are expected to work within a real-time, non-terminating environment. As well, agents can handle dynamically occurring events and may posses several processes to recognize and handle a variety of traffic patterns [3, 5].

By definition, a multiagent system consists of several agents working in cooperation within a single environment, towards a universal goal [7]. When applied to the urban traffic problem, individual agents provide the computational abilities of specific intersections, while others monitor the overall environment and coordinate actions between intersections. The coordination between agents is key to maintaining a balance between optimized events at a global and local level. An equilibrium between the two levels must be achieved [4] to ensure that improvements in one area of the network do not overwhelm and damage other aspects of the same environment.

Although several approaches to developing a multiagent traffic system have been studied, each stresses the importance of finding a balance between the desires of the local optimum against a maintained average at the global level [4]. Unfortunately, systems developed to only examine and optimize local events do not guarantee a global balance [6]. However, local agents are fully capable of determining their own local optimum. Therefore, a more powerful approach involves the creation of a hierarchical structure in which a higher-level agent monitors the local agents, and is able to modify the local optimum to better suit the global concerns [7].

The remainder of this paper is organized as follows. Section 2 examines the problems of current urban traffic systems. The design of a hierarchical multiagent model and communication protocols between agents are given in Section 3. Section 4 describes the creation of the multiagent environment and communication procedures. The experimental results are presented in Section 5. Finally, the conclusions of the present study are summarized in Section 6.

2 Challenges facing Urban Traffic

The first concern of any road network involves examining the current traffic systems to determine if they are capable of handling the daily movements of vehicles. Generally, it is only road networks of large, metropolitan areas that face the overwhelming problems of daily urban congestion. Often the structural layout of intersections and roadways within these cities cannot be further improved without increasing the size of the roads themselves. This is generally not possible, as most roads are situated between the pre-existing structures of an urban area.

2.1 Urban Traffic Congestion

Improvements to urban traffic congestion must focus on reducing internal bottlenecks to the network, rather than replacing the network itself. Of primary concern is the optimization of the traffic lights, which regulate the movement of traffic through the various intersections within the environment. At present, traffic lights may possess sensors to provide basic information relating to their immediate environment. This includes road and clock sensors, measuring the presence and density of traffic and providing the time of day to the traffic light.

The use of such sensors provides greater flexibility within traffic lights, since more appropriate patterns can be calculated for the current situation. However, these sensors are incapable of monitoring external events, or providing slow and gradual changes to the traffic flow. In addition, sensor information only passes to one specific intersection. As such, neighboring intersections are unaware of outside concerns, and may allow traffic to flow in a detrimental manner. When these problems occur, the processes within a traffic light will remain oblivious. The resulting congestion will eventually overwhelm neighboring intersections, increasing the congestion of the overall network.

2.2 Computational Requirements

To ensure the consistent functioning of any computational solution to the urban traffic problem, the fundamental characteristics of the environment must first be met. A vehicular traffic network is a non-terminating, real-time process. This requires that any proposed solution perform all necessary operations in sufficient time to avoid delaying other operations within the system. In addition, the processes to determine the next state of the traffic light must operate in a cyclical manner, as the traffic light will endlessly switch between all incoming directions. As a result, any solution will operate as an infinite loop or as a non-finite process.

A second issue of concern is the handling of dynamically occurring events, such as traffic accidents or the congestion of a roadway within the system. Although pre-existing plans can be developed to handle such events, it is not possible to predict their occurrences within the system. Therefore, the system cannot wait for the occurrence of an event; rather, it must be capable of acknowledging and then dealing with events as they occur.

A final concern facing computational requirements is the achievement of a balance between the local and global levels of the system. This is the most challenging issue facing any solution, as a system which focuses on one aspect alone often will lack functionality when viewed from the alternative perspective. Although a functioning system can be developed to ignore the global concerns, the local optimums of specific intersections can often lead to congestion for their neighbors. This leads to an imbalance at the global level.

2.3 Application of Agents

A solution to the urban traffic problem using agents is to simply replace all decision-making objects within the system by a corresponding agent. Even the most basic system will consist of several agents, leading to the creation of a multiagent environment. In this case, the traffic environment is broken down into its fundamental components, with one agent for each of the traffic lights within the system. To maintain organization and cooperation between the Local Traffic Agents (LTA), a Coordinator Traffic Agent (CTA) exists to monitor global concerns and maintain order. This structure is demonstrated in Figure 1.

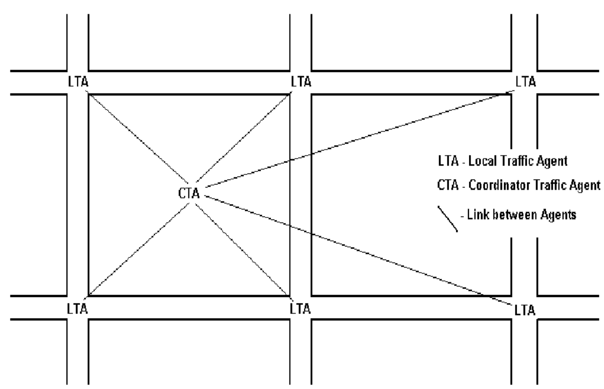

Figure 1. Layout of Local and Coordinator Traffic Agents

An advantage agents have over other possible solutions is the ease in which present-day traffic systems can be reproduced using agent technologies. Multiagent environments do not exist as terminating processes, and are expected to function indefinitely. A LTA is provided with the same information from road sensors as are current traffic intersections, allowing the agents to determine their optimal light pattern in a similar manner. In essence, a basic multiagent traffic system, consisting only of core capabilities, will function in a similar manner as contemporary traffic systems.

3 Multiagent Architecture

The development of a multiagent traffic system requires the construction of many agents and internal processes. While individual agents within the system are meant to handle the movement of traffic throughout specific intersections, there must exist some means of managing traffic at a global level. Achieving a global management of the multiagent environment can only be accomplished by sharing information between agents. This requires efficient communication protocols between all agents within the system. However, this brings into question the validity of the shared data, and the necessary security procedures to protect the multiagent traffic system.

3.1 Hierarchical Multiagent Model for Urban Traffic

To achieve a balance between the local and global aspects of an urban traffic system, a multiagent system based on a hierarchical architecture is proposed. Figure 2 illustrates the proposed multiagent system. LTAs and CTAs make up the fundamental levels of the hierarchy, in which the LTAs meet the needs of the specific intersection, and the CTAs determine if the chosen patterns of a LTA are suited to meet any global concerns. A solitary Global Traffic Agent (GTA) may exist for networks of sufficient size, and an Information Traffic Agent (ITA) provides a central location for the storage of all shared information within the system. For each agent, the variables necessary to organize and maintain the hierarchy are listed.

Information Traffic Agent: A solitary ITA exists to provide a central location for the storage of all information detailing the state of each intersection. This includes the direction in which traffic is currently travelling, and specifying the time that an intersection will remain in this state. The ITA also holds the road sensor data used to describe the traffic densities throughout the network. By storing this information in a single location, there is no chance that conflicting values will exist elsewhere in the system. To maintain the validity of the data, the ITA will require processes to

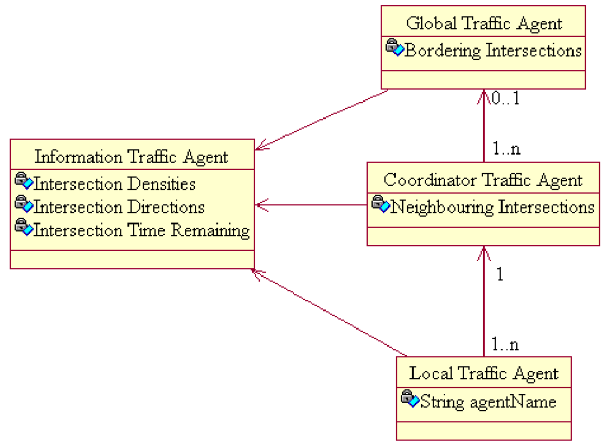

Figure 2. Hierarchical Multiagent Model

update, retrieve and return stored information as requested by other agents within the system.

Local Traffic Agent: The LTA is the fundamental component of a multiagent traffic system. Ultimately, the LTA is responsible for providing an appropriate traffic light pattern to their assigned intersection which allows traffic to pass. Contained within the LTA is an algorithm which interprets the local sensory data to compute an appropriate light pattern. This pattern represents the optimal local traffic light pattern for the intersection, as it is based solely on the concerns of the specific intersection. The algorithm used to derive this optimal traffic light pattern is irrelevant to the construction of the agent, provided the pattern returned is complete and understandable.

Coordinator Traffic Agent: As the number of neighbors an agent must contend with increases, it becomes more difficult for the LTAs to factor in all aspects of the environment. A CTA provides the means of monitoring the overall environment, while the LTAs continue to focus on organizing their local intersections. When a LTA displays signs of increased congestion relative to its neighbors, the CTA is responsible for informing the appropriate LTAs of this congestion, and have them respond accordingly.

The development of this system, in which several LTAs work under the guidance of a single CTA, represents the backbone to a hierarchical structure of agents within the system. The CTA provides the bonds between itself and the LTAs of the system, requiring that the CTA store a list of the neighboring intersections for each of the LTAs. However, the computational capabilities of a single CTA are limited, and a road network of sufficient size may require the use of multiple CTAs to handle all of the LTAs within the system. In this circumstance, the network will be subdivided into regions controlled by a single CTA, with a top-level Global

Traffic Agent (GTA) linking the CTAs together. The GTA is an optional agent, existing only if the network is sufficiently large that it is required.

3.2 Communication Protocols

The devised system involving local, coordinator, and information traffic agents requires extensive inter-agent communication capabilities. Communication protocols are necessary to pass information between the LTA and CTA, and to retrieve necessary information from the ITA. Communication between the ITA and all other agents is limited to retrieving and updating the information stored within the ITA. The ITA is not expected to perform any internal processes during this communication period, and should immediately provide the necessary feedback. Figure 3 demonstrates the communication links between agents, and the events called within an agent to pass the relevant information throughout the urban traffic multiagent system.

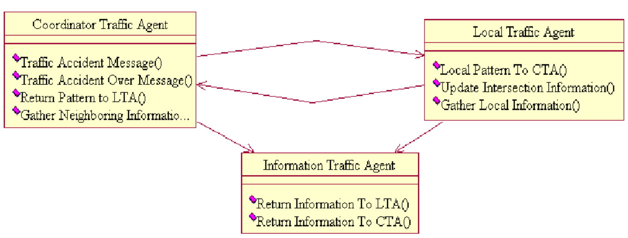

Figure 3. Agent-to-Agent communications

To maintain the hierarchical structure of the multiagent system, communication protocols do not exist between the individual LTAs within the system. A LTA interacts at a global level by sending a message containing the calculated optimal local light pattern to its supervising CTA. The CTA will find the appropriate neighboring intersections, and then determine what the global optimum for the handled LTA will be. To calculate the global optimum, the CTA will require all information relating to each of the neighboring intersection. The CTA will request the information from the ITA by providing a list of the intersections the CTA is concerned with. Once this information is retrieved, a CTA calculates the global optimum and determines if a variance exists between the local and global traffic light patterns. If a significant difference is found, a balance between the local and global optimums must be negotiated, and then returned to the LTA.

Communication protocols are also necessary to inform agents of the occurrence of events within the system. The majority of events within the system will affect only a small portion of the LTAs. Therefore, there is no need to inform all LTAs of the event, as this may create confusion amongst the LTAs, and waste valuable processor time. Only agents which the event has a direct influence over need to be informed. The CTA will determine upon which LTA the event has an impact, and will then notify those LTAs. Once a LTA has been notified of an event, it may choose to respond to the event in a variety of ways.

4 Implementation

The proposed urban traffic multiagent system has been implemented using the JACK Development Environment, utilizing $JACK\ Intelligent\ Agents^{TM}$. JACK uses the Belief Desire Intention (BDI) model. Under this framework, “the agent pursues its given goals (desires), adopting appropriate plans (intentions) according to its current set of data (beliefs) about the state of the world.” [1]. Agents created under the JACK environment are event-driven, and can respond to internal or external events occurring within the system

A feature unique to $JACK\ Intelligent\ Agents^{TM}$ is the way in which it manages inter-agent communication. Rather than using mobile agents to carry information between locally operating agents, JACK handles messages as a unique form of event. When an agent wishes to communicate with another agent, it creates a message event and sends it to the appropriate agent. The specified recipient of the message event must posses an event handler to recognize and address the incoming message event. If the recipient agent wishes to respond to the sender of the message, it can call upon the reply event method, which will return a corresponding message to the original sender. The use of events to deal with messages reduces the overall number of agents working within the system; however, it requires the development of several additional event handlers to acknowledge possible message events.

4.1 Creation of Agents

The first phase of implementing the multiagent system involves the creation of LTAs. Each of these agents are tailored to meet the requirements of its corresponding intersection. For the purposes of this project, the traffic network consists of six intersections. Each intersection consists of two roads crossing over one another. Each approaching road posses two lanes, a left-turning lane, and a straight/right-turning lane.

For this implementation, sensors measuring traffic density exist at the intersection. Having the sensors at the intersection allows the system to keep track of how many vehicles are currently waiting, and in which lanes. The information provided by traffic sensors are the inputs to the ITA. In this implementation, a user at runtime enters the awaiting traffic density for each of the intersections, providing a snap-shot of the environment. In a real-time environment, this would be modified to pass events to the ITA each time a vehicle passes over a sensor. This would allow the ITA to update the stored value. In addition to the sensor inputs, the ITA stores the current state of each traffic light, the direction of current movement, and the time remaining for the traffic light in its present state. With the relatively small size of this traffic network implementation, vectors are used to hold the data.

The decision-making capabilities of the LTAs is developed in the second phase. The first round of decisions by a LTA are concerned with finding the local optimum, with no consideration for neighboring intersections. A basic expert system divides the sensor inputs into a corresponding light pattern. The resulting light pattern consists of an eight-element array, which can be broken down into two elements for each of the North, East, South and West directions.

Traffic light patterns							
North going North East	North going West	East going East South	East going North	South going South West	South going East	West going West North	West going South

Odd elements of the array (zero is the first index) specify the duration of the advanced green state for each of the appropriate directions, while even elements indicate the time of the straight/right-turning lanes. This light pattern is always in the same format, and once calculated, stored by the LTA. The values contained within the array consist of strings, indicating the duration of the traffic light. The values of the strings are as follows:

Red: Red light, lanes remain in a stopped state.

Short: Green light, most frequently occurring, 30-seconds in duration for straight directions, 15 seconds for left-turning lanes.

Medium: Green light, often for above average traffic densities, 45-seconds in duration for straight directions, 25 seconds for left-turning lanes

Short: Green light, indicating a high traffic density, 60-seconds in duration for straight directions, 35 seconds for left-turning lanes.

Once the optimal local traffic light pattern is calculated, the LTA sends a message event to the CTA. The traffic light pattern is passed to the CTA, allowing the CTA to adjust the LTA's light pattern to better meet any global concerns. Stored within the CTA is a vector of neighbors for each LTA within the system. When a CTA receives a message event from a LTA, the CTA gathers all information relating to the neighbors of the currently handled LTA from the ITA. The CTA will use this information within its own expert system, comparing the local optimum light pattern against the current densities of the neighboring intersections. If a significant difference is found between the local optimum and the essence of the global optimum, the traffic light pattern to be implemented is altered to reduce the difference between the two optimums. The new traffic light pattern is returned to the LTA for implementation within the traffic light.

4.2 Handling Events

The final aspect of the urban traffic multiagent system involves techniques to manage dynamically occurring events within the system. This is where the primary advantage of a multiagent system becomes apparent, as agents provide a means of handling any foreseeable event. These events may override processes, allowing exceptions to the norm. Agents in this implementation are capable of handling two forms of events, involving the occurrence of traffic accidents, and the absolute congestion of a roadway within the environment.

Each LTA possesses a boolean variable to determine whether or not an event is currently active, and a list indicating the affected directions. This allows the agent to override the state of the traffic light pattern to be implemented, changing the way traffic is handled for any traffic lanes leading towards the affected directions. As long as the event remains active, all future traffic light implementations will be overridden to accommodate the event. When the LTA is informed that the event has passed, the agent will return to its standard operation.

Both events within this implementation result in similar modifications to the traffic light pattern. For either event, the overriding process of the LTA forces all light states allowing traffic to head towards the undesired direction to a red state. The traffic lane that allows vehicles to move in the restricted direction will act as a holding lane for all vehicles wishing to go in that direction. The other lane will take on the responsibility of moving traffic travelling towards the unaffected directions.

4.2.1 Traffic Accident Events

For implementation and testing purposes, an external user is responsible for notifying the CTA of the details concerning a traffic accident event. When a CTA is notified of a traffic accident, the CTA will determine which LTAs are directly affected by the event. These LTAs are then notified of the accident with another message event, allowing the LTA to respond accordingly. A LTA is deemed affected by an accident if the accident occurs at a neighboring intersection, a connecting roadway, or within the intersection itself.

4.2.2 Total Congestion Events

The total congestion event is an internal event called by the CTA. The event occurs when the roadway of a neighboring intersection of the currently handled LTA is absolutely congested, and cannot handle additional traffic. This is determined within the CTA, while comparing the traffic light pattern submitted by the LTA against the density values of the neighboring intersections. If a neighboring intersection is found to be congested, the CTA will check to see if an alternative route is available. For a roadway to be considered as an alternative route, it must be heading in the same direction as the congested traffic lane, and must be accessible at the neighboring intersection. If it is found that the alternative route is also congested, or if an alternative does not exist, then the CTA will set the traffic light of the LTA heading towards the problem area to a red state.

If a viable alternative route is found, the CTA will send a message event to the LTA. This results in the LTA overriding the adjusted pattern returned from the CTA for the soon-to-be implemented traffic light pattern. Once the traffic light pattern has been implemented, the event terminates and must be recalled by the CTA during the next cycle if it is to remain active. The total congestion event can act as a backup for the traffic accident event. If an accident occurs and the LTA is not informed, the directions leading towards the accident will eventually become congested. At this time, the total congestion event will occur, resulting in the LTA treating the affected directions in a similar manner as would occur due to a traffic accident event.

5 Experiments

This sections presents some of the experiments carried out for two fixed state scenarios. In each experiment, a list of variables is provided to initialize the current state of the environment. Once the state of the environment is established, each LTA goes through the process of changing the state of their traffic light to accommodate the other direction. The resulting traffic light pattern for each intersection is recorded, and the number of vehicles passing through the intersection, N, in the available time indicated by the traffic light pattern is calculated as $N = T/(\alpha + \epsilon)$, where α and ϵ represent the ideal amount of time required for a vehicle to pass through a traffic intersection and the latency increase to the ideal length of time due to unexpected events, respectively.

An advanced form of this calculation would allow the latency value of ϵ to increase by a constant factor for each additional segment of the waiting vehicles. This can be demonstrated by using β to represent each of the latency groups, imposing a maximum number of vehicles that exist within each latency group. Let The number of vehicles found in latency group k is calculated as,

$$\beta_k = \begin{cases} \frac{T-\sum_{i=0}^{k-1} t_{\beta i}}{\alpha+n\epsilon} & T-\sum_{i=0}^{k-1} t_{\beta i} > 0 \\ 0 & \text{otherwise.} \end{cases}$$

where t_{β_i} denotes the amount of time used by the latency group β_i. The total number of vehicles that could then pass through the intersection would be calculated as $N = \beta_1 + \beta_2 + \cdots + \beta_m$, where m represent the number of latency groups that can make it through the traffic light.

In this simulation we set $\alpha = 2$ and $\epsilon = 1$. A limit of three was imposed on the value of β_0,while no limit was imposed on β_1. These values were chosen for simplicity, and the precision in which the three possible values of T could be divided.

To display the traffic density of the network, a grayscale image representing the density values within the environment is used (see Figure 4). Each lane of the traffic network is covered with an appropriate grayscale image.

Table 1 shows sample traffic densities. Each row of the table represents an intersection within the network. The values of each field represent the waiting traffic density for each lane within the intersection. In this table N_s, N_l, E_s, E_l, S_s, S_l, W_s and W_l denote North straight, North left turn, East straight, East left turn, South straight, South left turn, West straight and West left turn, respectively.

Table 1. Sample Traffic Densities

Intersec.	N_s	N_l	E_s	E_l	S_s	S_l	W_s	W_l
1	5	1	10	4	2	1	3	6
2	6	2	12	0	1	4	3	2
3	2	4	5	1	6	2	2	2
4	1	2	7	1	3	2	2	1
5	2	1	8	5	0	2	4	3
6	2	0	7	3	6	1	1	0

To demonstrate the functioning of an intersection's traffic light pattern, the possible combinations of local and neighboring traffic densities are examined. Four cases exist for the local intersection, ranging from zero, to a high density. There are three possible densities for each of the neighboring intersections, ranging from a low to high traffic density. In table 2, intersection 1 is the local intersection, with intersection 2 and 4 representing the neighboring intersections. The intersections to the north and west are not contained within the network, and are considered unknown intersections. Traffic is heading in a north-south direction for the two known neighbors, with the local intersection changing from a north-south direction to an east-west direction. Since the traffic at the local intersection will be heading in

Table 2. Local agent information concerning environmental situations.

Local Traffic Agent	Coordinator Traffic Agent					
Intersection: 1 Direction: East-West Densities for concerned directions	Neighbors	Name	Traffic Direction	Densities		
				case 1	case 2	case 3
(East-straight, East-left, West-straight, West-left)	North	Unknown	—	—	—	—
local case 1: 0, 0, 0, 0	East	2	North-south	low	avg.	high
local case 2: low, low, low, low	South	4	North-south	low	avg.	high
local case 3: avg., avg., avg., avg.	West	2	Unknown	—	—	—
local case 4: high, high, high, high						

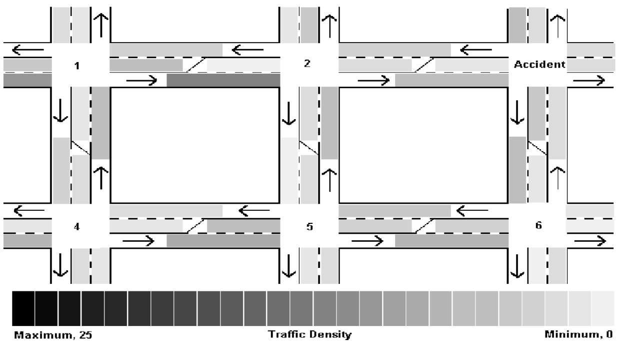

Figure 4. Initial densities prior to accident.

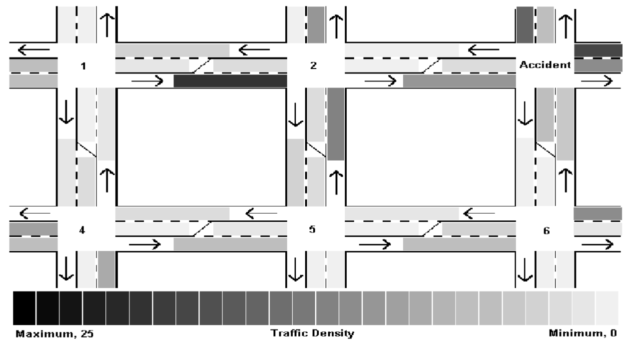

Figure 5. Densities after six cycles.

an east-west direction, the traffic light states managing the north/south directions will be red.

5.1 Traffic Accident Scenario

The traffic accident scenario involves the occurrence of a traffic accident in the upper-right intersection of the network. The accident is acknowledged by the CTA, allowing the adjacent neighbors of the accident to adjust their traffic light patterns to accommodate the event. Traffic flow continues at an average rate, leading to congestion of the adjacent intersections. Observations of the network are taken after each cyclical change of the traffic light to demonstrate the gradual congestion of neighboring intersections, and the manner in which the network handles the event.

The traffic accident scenario is initialized to simulate an average to low traffic density throughout the entire network. Each case involves the occurrence of a traffic accident at the upper-right intersection of the network. The network is initially built to simulate an average to low traffic density by setting the density values for each intersection to reduced values.

The occurrence of the accident results in the intersection at the upper-right to force all traffic to stop. This is done by implementing an all red traffic light pattern at the intersection faced with the traffic accident. The traffic light patterns of the adjacent intersections (2 and 6), remove their green states for the east and north directions respectively. Although traffic can still move in all other available directions, those vehicles planning to head towards the stopped directions are forced to wait at the intersection. This results in a gradual increase to the traffic density at the intersections adjacent to the accident. Figure 5 shows the densities after 6 cycles.

As the level of congestion increases at intersections 2 and 6, eventually their density values reach a point that leads to the CTA reducing the length of time that the other intersections (1 and 5) allow traffic to proceed. This results in a decrease to the overall congestion at intersections 2 and 6. Although slowed down, the density values will eventually reach their maximum level, at which time the totally congested event occurs. This forces intersections 1 and 5 to stop allowing traffic to move towards intersections 2 and 6.

By the eighth cycle, the traffic accident is cleared up. With the passing of the accident event, the LTAs are notified. During the next cyclical pattern, intersections 2 and 5 permit the congested lanes to move towards the intersection with the accident. This results in the traffic lanes of intersection 3 reaching a maximum density value. By the fourth cycle after the accident, the build-up of congested vehicles moving towards intersection 3 has been reduced, and the

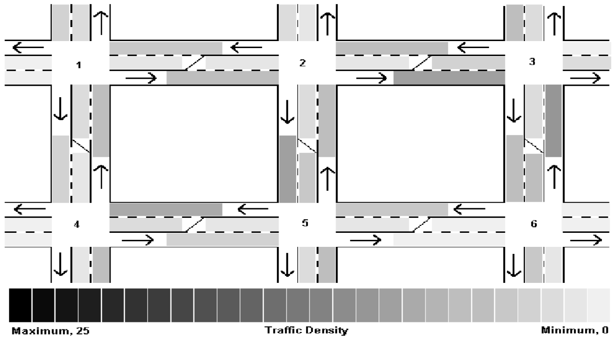

Figure 6. Densities five cycles after the accident is cleared up.

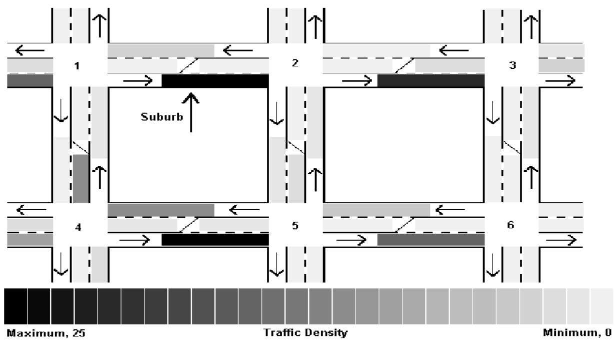

Figure 7. Densities after ten cycles.

intersections return to their normal functioning state. Figure 6 shows the traffic densities 5 cycles after the accident is completely cleared up.

5.2 Morning Rush Hour Scenario

To initialize the morning rush hour scenario, the traffic densities of the network are set to low values Over the next several cycles, a constant movement of incoming traffic is seen from the unknown directions, and from the suburbs located between intersections 1 and 2. With the addition of traffic from the suburbs, by the end of the second cycle, the east-bound lane of intersection 2 is heavily used.

When both east-bound directions for intersections 2 and 5 are fully congested (see Figure 7), traffic heading in those directions will be forced to wait. This will allow the east-bound directions of intersection 2 and 5 to reduce their traffic densities, which will allow traffic to approach these lanes during the next cycle. Until one of the east-bound directions is de-congested, traffic will not be diverted in a north/south direction to travel around the problem.

As rush hour passes and the inbound traffic density is reduced, the network is able to clear out the congested intersections This is done from east to west, as the rush hour traffic is proceeding in an eastward direction.

6 Conclusions

The development of a hierarchical multiagent structure to manage an urban traffic system is presented in this paper. To test the functionality of the proposed urban traffic multiagent system, two traffic scenarios are considered. For both scenarios (traffic accident and morning rush hour), the multiagent system efficiently managed the gradual congestion of the network. As one roadway becomes more congested, the duration of the traffic lights of neighboring intersections leading towards the congested area are reduced by the CTA. This redirection proves successful and results in the achievement of a global balance between the roadways of the network. However, when the traffic density continues to build, all roadways heading in a similar direction will eventually become equally congested. The urban traffic multiagent system handles this situation by halting all traffic heading in those directions. This allows the congested roadways to decrease their density values. Although this slows the network down, the congested traffic is handled in a more organized and controlled manner.

7 Acknowledgments

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