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Agent Based Simulation of ITS for Urban Traffic Control Using GPS

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Abstract

Intelligent transportation systems (ITS), especially in metropolitan areas, can play a crucial role in reducing traffic and its flow and finally reducing the average travel time of vehicles. Due to the high capabilities of intelligent agents in modeling and simulation, they have been used significantly to model complex urban environments and traffic control systems in recent years. In fact, base operating systems are appropriate for modeling intelligent transportation systems, especially in changing urban spaces, and simulating related facilities and equipment. However, most researches in this area have not been comprehensive. As it was mentioned, in this research, a comprehensive agent-based modeling of intelligent urban transportation system is used to control and manage urban traffic using instantaneous traffic information of streets and finally various scenarios have been proposed and implemented. Also, all vehicles have been equipped with GPS and communication devices are simulated. In this study, more emphasis has been placed on intelligent traffic lights using traffic information than routing methods using traffic information and the results have shown high effect of the smartization of traffic lights compared to the change in vehicles routing methods in management and reduction of urban traffic in implemented scenarios.

Keywords: Intelligent agent, Urban traffic, Intelligent transportation system, Traffic control.
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1. Introduction

The urban environment has long received much attention by researchers and managers in this field due to its high complexity and various related issues. Traffic is one of the most important and

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prevalent urban problems, namely in metropolitan areas, which we encounter every day. Many efforts have been made to solve this problem and several solutions have been presented, but because the complexity and parameters of this problem are high and diverse, each of them is considered as a local solution and is not a general answer [1].

Therefore, the move towards the use of new, early-return and low-cost methods to solve the problems of the transportation sector has been increased in recent years. Using intelligent transportation systems (ITS) is among one of these methods. ITS uses progress in computer technology, communications and sensor technology to convert urban and road transport into an efficient, available, integrated and managed system. Information is the central element of ITS and all ITS functions can be implemented with effective and adequate use of instantaneous traffic information [2].

On the other hand, agent-based computing is one of the strongest technologies for the development of complex distributed systems. Many researchers believe that intelligent agents have provide a very important model for software development after object-oriented design, and the concept of intelligent agents has a diverse range of applications in industry, instantaneous control systems, e-commerce, network management, intelligent transportation systems, information management and scientific computing [1]. Intelligent agent technology can examine, analyze, and improve the collaboration ability and distributed computing capabilities of centralized information systems at ITS, especially via simulation and scenario building, interoperability. Distributed base operating systems can combine information from multiple systems and tracking stations, simulate and evaluate traffic flow, and evaluate practical responses to traffic flow changes instantly, and are used in many areas and aspects of intelligent transportation and traffic systems including modeling and simulation, dynamic routing, traffic jam management and intelligent traffic control are used [2].

As it was said about the issues and problems in urban transportation, especially in traffic jam and the resulting pollution, as well as the capabilities and applications of base-agent systems for ITS modeling and simulation, it was decided that in this research, the capabilities of intelligent agents can be used in the dynamic and variable environment of the urban transportation system to solve a small part of the problems in this area, especially in traffic reduction and we can also make these methods as practical. A lot of research has been done on control and monitoring of instantaneous changes in urban traffic and its management, which is one of the main topics of this paper. Some of the studies are mentioned as:

Various researches have been conducted around the world regarding the control of urban intersections and traffic lights. Sandhu et al., have proposed some models for urban traffic control based on a number of intelligent traffic lights and road agent [3]. Srinivasan and Choy have proposed a single-layer multi-agent structure to control traffic lights with dynamic assigning of areas covered by agents [4]. Khamis & Gomaa have presented a multi-agent framework for controlling traffic lights using interactive multi-criteria functions [5]. Abdoos et al., have developed a multi-agent system for controlling traffic lights in a large urban traffic network. To reduce the problem complexity, they have divided the network into a number of zones, each of which includes several intersections, and have considered some agents at two levels for area control and intersection control, and have presented their own model [6].

In the modeling and traffic simulation section, especially in the section of modeling drivers' behavior and decision making to choose the optimal route, Dia used a agent-based method for modeling drivers' route selection behavior using real-time traffic information according to the behavior pattern of drivers guided by a global communication route [7]. Adler et al., proposed interactive traffic management and rout guidance systems based on the integration of multi-agent systems [8]. Galland et al., have proposed a multi-agent model to simulate driver behavior in urban environments using the Janus platform and have also proposed suggestions to reduce design complexity [9]. Melnikov et al., proposed an agent-based traffic simulation system for comparison with transport network environmental sensor data in critical situations [10]. In other sectors of the urban transportation system, such as modeling the behavior of pedestrians in Szymanezyk, O. & Dickinson study [11], safety at intersections of Salim et al. [12], intelligent traffic control systems of Lu and Chen [13] etc. have used the capabilities of intelligent agents, which are out of the scope of this study.

As mentioned, various researches have been done in the application of intelligent agents in ITS modeling and simulation in order to control and monitor urban traffic. However, a few studies have conducted about the comprehensive and practical modeling using intelligent agents and further studies are required in this field. Therefore, in this research and in the presented model, both the issue of intelligent traffic lights at intersections and the dynamic routing of vehicles and drivers' behavior in different traffic situations using real-time network traffic information obtained from Global Positioning System (GPS) and its effect on reducing the average travel time and consequently reducing traffic in the entire urban transport network have been dealt as one of the main purposes. Finally, one of the best intelligent agent platforms, Java Agent Development Framework (JADE), and its class library has been used to implement the model due to the complexity of the urban environment. Also, another important purpose of this research is to simulate information and communication interaction between components of urban traffic space.

New aspects of this research compared to the reviewed research can be summarized as follows:

a) In the present study, the simultaneous smartization of traffic lights and vehicles was done using a third central agent and in different scenarios the effect of each of these two separately and together have been studied and compared, but in previous researches, only one of the aspects or elements of the ITS system has been modeled and simulated as agent-based. These studies include researches done by Srinivasan and Choy [4], Dresner and Stone[14], and Jin and Ma [15] to control and manage the agent-based traffic light and intersections, as well as Dia [7] and Weyns et al. [16] for modeling the agent-based vehicle routing in the network. More comprehensive cases have not been the agent-based, which can be referred to the research carried out by Taale et al., to integrate traffic light control and route guidance in the transportation network [17].

b) Most of the agent-based modeling done in the researches, has provided a framework and agent-based structure for modeling network components and less scenarios have been made in this regard. However, in this study, in different scenarios, as described in Section 3.3, a decline of up to about 29% has been occurred in the average travel time across the network compared to normal case. Of course, other researchers have done something in this regard, which can be referred to the research done by Srinivasan and Choy [4]. In the study, several traffic light control models were compared in terms of average delay to reach the destination of vehicles. Finally, the comparison of these models shows a maximum difference of 35% between the best and worst models and the percentage of delay reduction to the normal situation is not stated. In some cases, some researches have been done to improve agent-based models for traffic simulation or predict traffic conditions and compare the results with real data, and the average trip time and distance traveled have been measured quantitatively, but, scenarios and comparisons have not been made to find a better method as what we have considered in the present study. One example is the research done by Melnikov et al. [10]. Their research results show a difference of about 9% and 2%, respectively in the average trip time and the average travel distance by the agents with the actual data obtained by the network sensors. We can also refer to the research conducted by Chen and Rakha who also developed a multi-step prediction of experienced travel times using agent-based modeling, at travel times in the transport network using previous and instantaneous traffic data, and finally their model shows an error of about 9% in travel time's prediction [18].

c) Also in this research, it is assumed to use GPS system in all vehicles to access instantaneous traffic information and for this purpose, the access of all vehicles to this system is simulated, which is a prospective approach.

2. Materials and methods

According to the purpose mentioned in the previous section, in this research, a simple urban transportation system with simple traffic regulations with multiple streets and intersections and three types of agents were considered. The agents considered are:

1. The main agent as the traffic control center and data collection of ITS system
2. Mobile agents as a vehicle
3. Traffic light agent with the ability to exchange information with all other agents

2.1. The main agent as the center of traffic control and data collection of ITS system

A main agent is predicted in this software to play the role of traffic control center. To create the role of the traffic control center in the main agent, all other agents, which are the cars, send an instant message containing their instantaneous coordinates to the main agent and notify it of its current coordinates. Therefore, the main agent is able to continuously respond to requests from other agents, including requesting information about the traffic situation of a particular street at that moment.

2.2. Mobile agents as vehicles

2.2.1. Simulation of GPS system in cars

A GPS simulator system is implemented in the software that simulates the equipping of all vehicles with GPS. In this simulator system, a moving vector is assigned to each mobile agent based on the velocity determined for it. Therefore, each mobile agent changes position according to its instantaneous velocity as much as it's moving vector in the simulation environment. Therefore, the mobile agent applies the length of the vector to its previous coordinates at each stage of the displacement in the simulation environment and obtains its new coordinates. Therefore, the mobile agent has access to its coordinates at any time, and we can say equipping of all agents to GPS system is simulated.

2.2.2. The movement method of agents and adjusting their speed in the environment

For correct guidance of vehicles, it is necessary that the right or wrong decision of each mobile agent in choosing the route to be in favor or to his detriment. In other words, he can move faster due to the right decision and going to a quiet path, and instead he can slow down due to the wrong decision and going to a crowded path. This is considered due to high consistency of the agents' movement conditions with the actual movement of vehicles in the real environment. In this regard, a coefficient is considered which is calculated by the main agent and sent to each mobile agent. This coefficient is actually the average number of mobile agents crossing each street in 10 seconds, which is sent once every 10 seconds for mobile agents in terms of their street location. This coefficient is calculated by the main agent because the main agent is aware at all times of the coordinates of the mobile agents and the traffic situation of each street. Each mobile agent also places this coefficient in Equation (2.1) and adjusts its new speed according to the result obtained [19]. Of course, in the main relation of this coefficient, namely Flow coefficient, the average passing traffic is in five minutes, which according to the considering 10 seconds in the present research, the formula has changed accordingly. Also, in the main Equation, instead of V1, there is a constant number of 39.8 km / h, and to use this formula, the initial speed of the mobile agents was considered so that their average is equal to this value in km / h .In this way, its speed is different according to its correct decision and entering a less crowded street or vice versa.

$$V(x) = \frac{V_1 - 6.06 \times Flow + 5.28 \times Lanes}{3.6} \tag{2.1}$$

where $V(x)$ is the secondary velocity of the mobile agent due to the new traffic situation in meters per second, V_1 is the initial velocity of the mobile agent after conversion to kilometers per hour, Flow is the coefficient or average number mobile agents crossing the street where the mobile agent X is located 10 seconds and Lanes as the number of lines or lanes of the street is equal to 2 according to the design considered for the streets.

2.2.3. Algorithm and method of routing mobile agents in the environment

A powerful and efficient ITS system should be able to monitor the transport network environment instantly and provide the necessary conditions, including access to real-time traffic information to select the right route for drivers to reach destination. Two scenarios were considered for routing mobile agents in design. The decision in the first scenario is made without the use of traffic information only based on network distance. In the second scenario, a decision is made by asking the main agent at the intersection about the traffic on the streets or the links of the routes between that intersection and the desired destination at a specific time in the past, which is 10 seconds. In other words, the agent examines the 3 available routes at each intersection to reach the specified destination based on familiarity with the environment and having a map, or choose his route only based on network distance or simultaneous use of distance and network traffic status information. The reason why the restriction of 3 routes was considered, one was to reduce the complexity of implementation and the other is that in reality, people usually consider specific and limited routes in choosing the route and many of them don't use deviated routes even with less traffic.

2.2.3.1. The lack of using instantaneous traffic information in routing by mobile agents . If the mobile agents do not use the traffic information, the mobile agents select the minimum network distance to the destination from the 3 available routes and continue their route based on it from their place at the intersection.

In fact, as the mobile agent has access to its instant coordinates and on the other hand also has access to the length of the streets by having a map and familiarity with the environment, selects the shorter route and moves to the destination from among the 3 routes to the destination, based on calculating the total length of existing streets in each route.

2.2.3.2. Mobile agents using instantaneous traffic information in routing. If mobile agents use traffic status information in routing, when reaching the intersection, in addition to considering the distance component, consider the average number of mobile agents entering the streets or links of the 3 routes specified between that intersection and the given destination in the previous 10 seconds in the route selection. Thus, each of the three routes determined from each intersection to the destination may include one or more streets. The moment the mobile agent is at the intersection and behind the red light, it requests the number of cars entering all the streets of each of the three routes separately in the previous 10 seconds from the main agent. Then calculates the average number of cars entering the streets of each route and places it as a flow parameter in Equation (2.1) of Section 2.2.2, and therefore calculates its average velocity in each of the 3 possible routes and with considering the length of the route and the average speed, calculates the probable time to reach the destination. So the mobile agent chooses the route that will probably take the least time to reach the destination.

2.2.3.3. Function used to select the route at intersections. The function that determines the direction of movement at intersections is shown as Equation (2.2):

$$F(X) = \begin{cases} d, & \text{Use Traffic Data} = \text{False} \\ \frac{L}{Vavg}, & \text{Use Traffic Data} = \text{True} \end{cases} \tag{2.2}$$

Where $F(X)$ is the computational function of the mobile agent X, d is the network distance of the mobile agent to the destination, L is the total length of each of the 3 routes and Vavg is the average calculated velocity of the mobile agents in each of the 3 routes according to the traffic status information of the route.

Therefore, each mobile agent, depending on whether or not it uses traffic status information in routing, which is True or False status mentioned in Equation (2.2), uses this function to find the optimal path that is the path with low weight. Thus, using the traffic status information of the route is having low network distance and when using the traffic information of the route means the route with less travel time.

2.3. Traffic light agent to control the intersection

2.3.1. Distributed processes based on traffic light position

In this research, it was attempted to consider the distribution in calculations and processes between agents, especially in the case of traffic light agents, more than in the previous research, in which the intelligent control methods of intersections have also changed [20]. For this purpose, it was intended that each traffic light be equipped with a map of the streets leading to it, but only half of the street where cars are moving towards the crossroads. By doing this, part of the processing will be removed from the main agent and will be left to the traffic light agents. On the other hand, it was considered that the mobile agents send their instantaneous speed to the traffic light agent they are moving towards, which will also be effective in better distribution of processes among the model agents.

2.3.2. Methods considered for intersections control by traffic light agents

The traffic light agent controls the intersection by four methods:

1. Normally and without considering the instant information of traffic situation
2. The method of calculating the maximum number of cars that reaches the intersection from among the four sides
3. The method of calculating the minimum average time for cars to reach the crossroads among the four available sides
4. The method of calculating the maximum average stopping time of cars behind a red light among the four available sides

2.3.2.1. Normal method and without considering the instantaneous traffic situation information . In the first method, the green light is shifted in four directions based on a fixed and definable time, as there is no specific intelligence in this method and is implemented only for comparison. Given that the simulation environment is vector and as a result the movement of agents is also in the vector environment, each mobile agent before each vector movement, estimates whether it reaches the intersection or not. In fact, the mobile agent does this by knowing the instantaneous speed and consequently the length of its moving vector, as well as by calculating the distance to reach the intersection with its coordinates and the environment map. If the answer is yes, it stops and asks the traffic light operator to send a message in that route, and if the light in that path turns green, the traffic light agent sends a message of permission to move, and if the light turns red, a message of no permission to move is sent.

2.3.2.2. Method of calculating the maximum number of cars reaching the crossroads from the four sides. In this method, the light continues to be green on one side for a certain period of time and this time can be changed by the user. During this period, which is considered to be about 10 by default, if the mobile agent reaches the side of the intersection where the traffic light has turned green according to its calculations, the mobile agent sends a message to the traffic light agent and to move and after receiving it, continues on its selected route. Otherwise, if the mobile agent stays behind the red light, by sending a request for permission to pass by the mobile agent and receiving it by the traffic light agent, the traffic light agent will not allow the passing and that agent is added to the list of agents behind the red light. On the other hand, by having the speed of mobile agents and requesting the traffic light agent from the main agent to access the coordinates of the mobile agent in the four edges connected to the street and receiving their coordinates, the traffic light agent can calculate their distance to the intersection and by having their speed, calculates the number of agents reaching the intersection within 10s from each side and add it with the number of mobile agents behind the red light on the same side, and finally after the end of 10 seconds and when deciding to choose the green direction of traffic light, that direction will be green that the sum of the mobile agents that are left behind from the other side of the light, as well as the mobile agents that will reach the intersection from that side in the next 10 seconds, is the maximum value among four sides. It is necessary to mention that the traffic light agent requests the coordinates of the mobile agents from the main agent and calculates it later until it reaches the number of agents that reach the intersection in 10 seconds in the last second before selecting the direction of green light.

$$n_i = \max(j)\left[m(j) + \text{number of } i \text{ that} \left(\frac{d(i)}{CSA(i)}\right) < 10\right] \tag{2.3}$$

Where n_i is the maximum number of vehicles reaching the intersection from the four sides, j is the number of the area or street connected to the intersection, i is the number of each mobile agent in one of the four areas connected to the intersection, $m(j)$ is the number of vehicles behind the street lights, $CSA(i)$ is the speed of the mobile agent i in that area and $d(i)$ is the distance of the mobile agent i in that area to the intersection at that moment.

2.3.2.3. Method of calculating the minimum average time for cars to reach the intersection among the four available sides. In this method, the traffic light agent is determined based on the average time of arrival of cars or the same mobile agents to the intersection under its control for the traffic light to turn green. Thus, after the end of the green staying period, which is 10 seconds by default, the traffic light agent asks the main agent for the coordinates of the mobile agent of each of the four edges or the street connected to it from the main agent and after having access to this information and having their speed, calculates the time to reach the intersection for all mobile agents. Then, the traffic light agent calculates the average arrival time of the vehicles for all four streets, and among them, the lowest average time for each of the edges or connected streets, the light of the same direction turns green, and the mobile agents of that street are allowed to pass. In this method, the agent uses Equation (2.4) to determine the direction of turning green.

$$MMT = \min(j)\left(\sum\left(\frac{d(ij)}{CSA(ij)}\right)/n(j)\right) \tag{2.4}$$

Where MMT[1] is the lowest average time of arrival of vehicles from the four sides of the intersection, j is the number of the area or street connected to the intersection, i is the number of each mobile agents in one of the four areas connected to the intersection, CSA[2](ij) is the velocity of the mobile agent i^{th} in the area or street j^{th}, $d(ij)$ is the distance of the mobile agent i^{th} in the j^{th} area up to the intersection and $n(j)$ is the number of mobile agents on j^{th} street.

According to this relationship, the distance of each of the mobile agents in each of the streets connected to the intersection is calculated and divided by their instantaneous speed, therefore the time of arrival of each of them to the intersection is calculated. Then the averaging is made, in which the best direction of turning green is obtained, and therefore that direction turns green at the end of previous 10s by the traffic light agent.

As in the previous method, if the streets connected to the intersection are quiet at the decision making moment, the selection is done normally and the green direction continues as clockwise.

2.3.2.4. Method of calculating the maximum average stopping time of cars behind a red light among the four available sides. In this method, it was considered that based on the average time that cars are waiting behind the red light, the selection of the direction for the green light is done by the traffic light agent. This method considering the number of cars behind the traffic light is appropriate and can help drivers' mental comfort due to less stopping behind red lights and less exposure to traffic in general, because in the method of number of cars, some of mobile agents may reach at intersection with a number of mobile agents together or at very short intervals, and the traffic light agent will turn the traffic lights green just because of their diverse numbers, while there may be fewer mobile agents on the other side of the intersection awaiting behind the red light for a long time and stay again behind the red light. The calculation of the average time when cars are behind a red light is based on the communication mechanism of mobile agents with the traffic light agent, which has already been stated. In this way, when each mobile agent reaches the intersection, it sends a message to the controlling traffic light agent for passing, and if the controller light of the street where the mobile agent is located is green, the traffic light agent allows the mobile agent to pass , therefore that agent is removed from the list of mobile agents behind the light. Otherwise it is not allowed to pass and the traffic light agent stays behind the red light until the light turns green. Therefore, the traffic light agent with this communication mechanism knows both the number of cars behind the red light and the length of time each one stays behind the traffic light in each of the streets leading to the intersection, hence, it can calculate the average time of cars stopping in each direction and turns the direction green at the end of 10 seconds, which has the highest average time. Equation (2.5) is applied to calculate and select the direction of turning green in this method.

$$MMT = \max(j)\left(\frac{\sum t(ij)}{n(j)}\right) \tag{2.5}$$

1. Min Mean Time
2. Current Speed Of Agent

Where MMT[3] is the maximum average stopping time of the four sides of the intersection, j is the number of the area or street connected to the intersection, i is the number of each mobile agent in one of the four areas connected to the intersection, $t(ij)$ is the stopping time of the mobile agent i in the area or street j^{th} connected to the intersection behind the red light and $n(j)$ is the number of mobile agents behind the traffic light in the area or street j connected to the intersection.

3. Results and Discussion

NetBeans software and programming environment was used in implementation. In fact, agent-based capabilities of JADE platform and the NetBeans programming environment have been used in implementation and execution. JADE is actually a platform for agent-based development based on the Java programming language. So for programming in Java , the NetBeans programming environment is used as the IDE[4]. Figure 1 shows the main elements of JADE architecture [21].

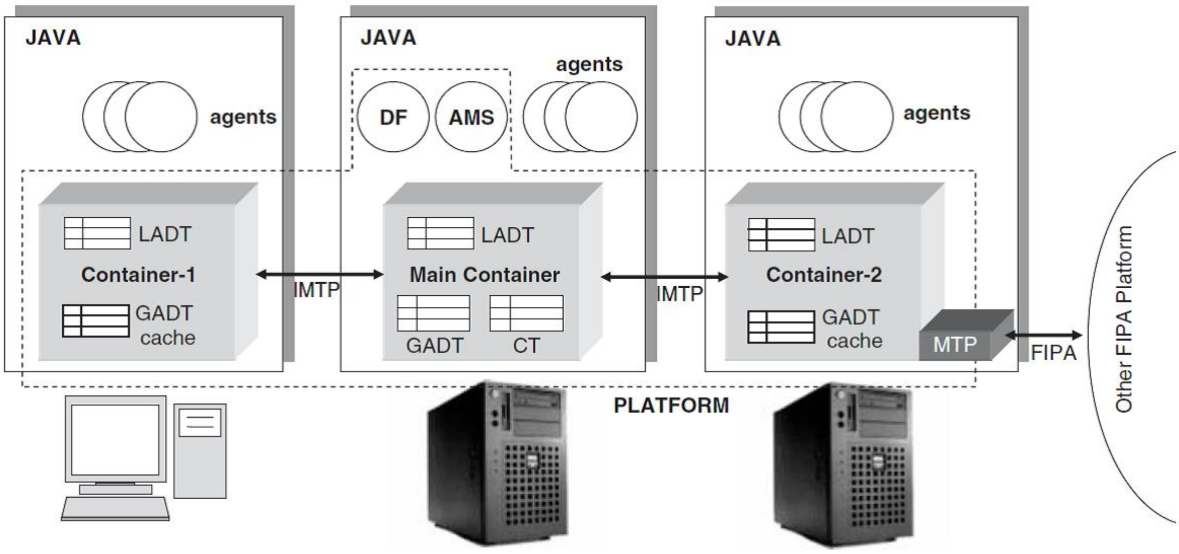

Figure 1: The main elements in JADE architecture

The main classes in the program are named based on three important agents of the model, namely main agent, mobile agent and the traffic light agent. The simulation environment used is also a vector environment that was easily made possible by using the powerful JADE platform. The designed graphic user interface also allows the user to select the desired scenarios. It is attempted to make using the user interface easier by the user It is also possible to see the status of each mobile agent and its characteristics such as instantaneous, initial velocity, instantaneous coordinates and destination of the agent are predicted. Due to the lack of access to valid data from the urban transportation system, the data used are simulated in the data model. The input data includes the origin coordinates of each mobile agent, the initial velocity considered for each agent to move in the environment and their destination coordinates enter into the model in file in txt format. Figure 2 depicts the method of observing instantaneous information of mobile agents.

3. Max Mean Time
4. Integrated Development Environment

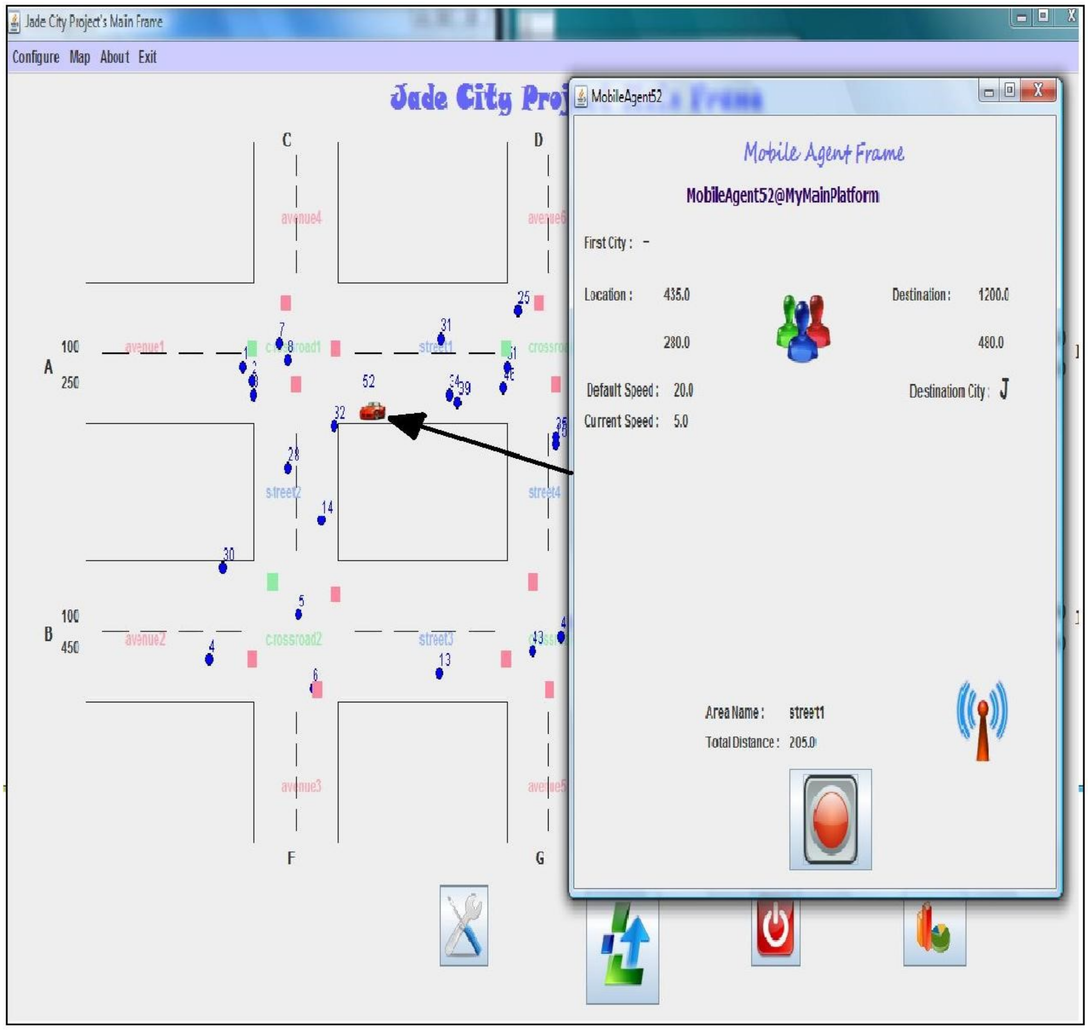

Figure 2: Observe instantaneous information of mobile agents

As shown in the figure, the mobile agents are moving in the environment as blue points with their number. Therefore, according to the selected scenario for the operation of the agents, it is possible to track each agent in the environment and visually compare their behavior during execution by the user.

3.1. Simulation environment and routing method of mobile agents

In designing the simulation environment, three types of areas have been considered. The first is private avenue, which is actually all streets that connect from one intersection to one of the ten destinations for mobile agents. The second is the crossroad, which is between four lanes. These crossroads are the decision-making place of the mobile agents, meaning that the agents in these areas decide about one of the three given routes and choose the route. The third is street, which is actually the area that connects the two intersections. Figure 3 shows the movement areas in the simulation environment and an example of 3 paths and estimating the distance to the destination.

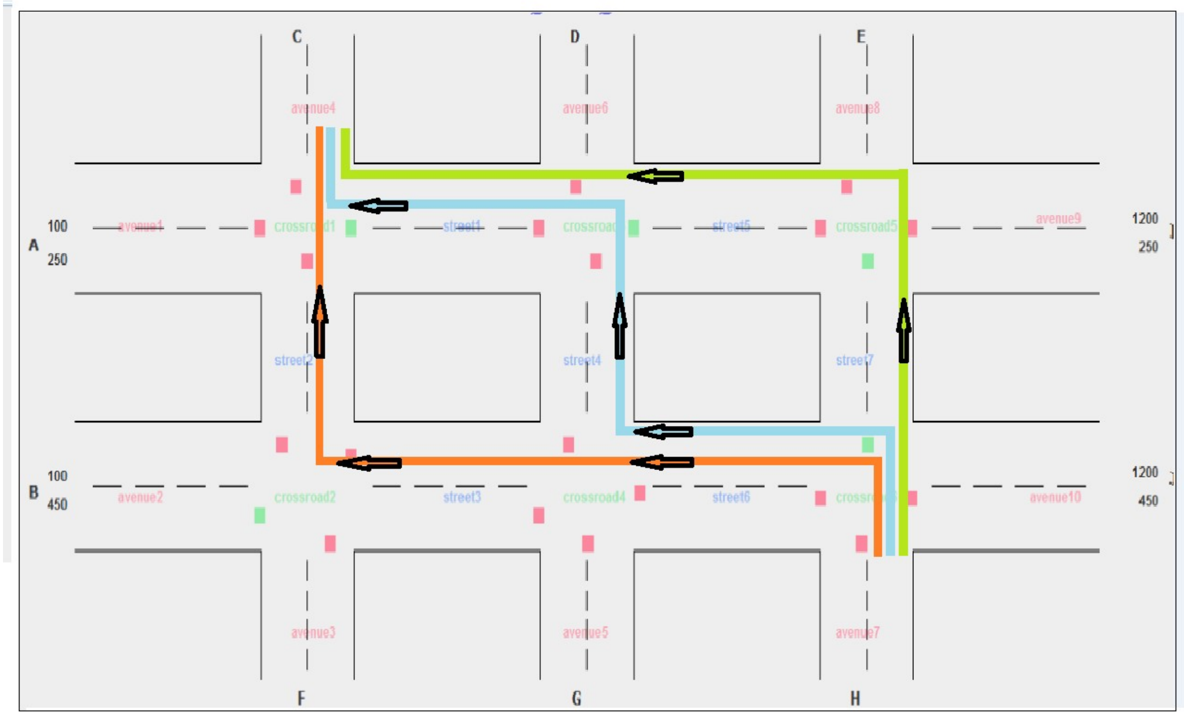

Figure 3: Movement areas in the environment and an example of 3 routes and estimating the distance to the destination

3.2. Scenario building

One of the important capabilities of agent-based modeling is its ability to build scenarios. In fact a series of parameters are added to the model before execution and the desired methods will be selected based on which the model is implemented. These parameters include the default duration of traffic lights or the number of mobile agents to be determined by the user. It is also possible to select the various methods of mobile agents as well as the intersections control by traffic light agents mentioned earlier and in the previous sections.

Therefore, the mentioned parameters and methods can be changed before execution and the results can be investigated and analyzed. The results are also observed as graphical during the program execution and as the report during execution and after it.

Therefore, as mentioned, by creating a scenario, i.e. entering parameters and selecting methods and entering data into the system that are done via the graphical user interface, the mobile agents and traffic light agents are created and start making decisions and work in the simulation environment to achieve their required goals.

During the execution and also at the end of the simulation, the results can be analyzed both visually and graphically and as a report. The results of the execution are displayed in the form of a table. The information in this table includes the basic information of each agent and the distance and time traveled by it, as well as the average time and total distance traveled by all mobile agents.

3.3. Results obtained after implementation

After entering the data and the system implementation by them and in different methods or scenarios, the results were obtained according to Table 1.

Table 1: The results of different executed scenarios

Scenario number	Implementation method (scenario): Crossroad control method: Normal	The maximum number of cars	The lowest time average of reaching the agents	The highest average of stopping time	Agents routing method: Without using traffic information	With the traffic information	Total simulation time (s)	The sum of distances taken by the agents (m)	The trip time average of agents (m)
1	√	-	-	-	√	-	276.432	83429.65	168.92
2	-	√	-	-	√	-	257.581	83190.83	149.13
3	-	-	√	-	√	-	270.765	83396.23	140.76
4	-	-	-	√	√	-	251.851	83538.11	130.17
5	√	-	-	-	-	√	266.830	87653.94	159.48
6	-	√	-	-	-	√	258.941	85943.76	133.84
7	-	-	√	-	-	√	281.942	86923.32	137.23
8	-	-	-	√	-	√	277.742	83912.35	119.95

Based on the study of the results of this table, the following can be extracted:

- The first four rows of the table are related to the state in which the mobile agent performs routing without using traffic information and is done only based on the network distance from the destination. Comparison of the first rows and the next four rows of the table indicates that crossroad control using three methods other than the normal method by the traffic light agent reduces the average travel time of all mobile agents, compared to the normal state of crossroad control.

- Similarly, cross road control by the highest number of cars and the lowest average time methods reduces the total simulation time and the maximum average of stopping time method can increase it compared to the normal state.

However, this criterion is not of great importance, because it states how long it takes for the last car to reach its destination, and sometimes it happens that the last car arrives at its destination much later than other cars.

- Comparison of the second to fourth rows of the table indicates that crossroad control by the maximum average of stopping time method causes much significant decrease in the average travel time of all mobile agents, compared to the normal crossroad control state compared to the other two crossroad control methods.

- In this way, the crossroad control by maximum average stopping time by the traffic light agent causes a significant reduction in the total simulation time compared to the other four states.

- It is interesting that in the first four states, i.e. the first to fourth rows, the total distance traveled is almost constant and the difference is very small. This is logical, because in these four methods, different routes are not traveled by mobile agents, and mobile agents move towards the destination only based on the shortest distance, without using traffic information.

- The last four rows of the table are related to the situation in which the mobile agent performs routing using traffic information in combination with the network distance to the destination. In fact, the mobile agent, having the length of 3 selected routes and calculating its probable speed in these routes, chooses the route according to the traffic situation. It is worth to mention that routing using traffic information by the mobile agents in two cases, i.e. the seventh and eighth rows can increase the total simulation time compared to the normal state of intersection control, i.e. the fifth row, and even compared to the normal state of crossroad control without using traffic information –the first row. The reason for this is that, as mentioned, sometimes the last car arrives at its destination much later than other cars. In other words, modification and reduction of the average travel time for the total set of mobile agents is not the reason for reducing this time for each of them.

- The comparison of the second four rows in which instantaneous traffic information is used in routing and the first four rows in which instantaneous traffic information is not used in routing shows that routing methods using traffic information by the mobile agent has reduced the average travel time of all mobile agents, compared to routing methods without using traffic information, as this reduction is also significant in some cases. Of course, as shown in the results of the table, this reduction means the reduction of the average travel time in the corresponding methods, i.e. methods with the same crossroad control mechanism, for example, the sixth and second rows. This indicates that the use of instantaneous traffic information obtained from GPS in the cars routing can have a positive effect on reducing the average travel time in the urban transport network, which is one of the goals of the ITS system.

- Another interesting point is that in the last four rows, compared to the first four rows, the total distances traveled by mobile agents have increased somewhat. This issue was predictable, because in routing using traffic information, mobile agents choose the less crowded routes at the expense of short paths.

- Comparison of the last four rows of the table shows that in routing using traffic information, crossroad control by the maximum average stopping time method causes a significant reduction in the average travel time of all mobile agents than the other two methods compared to the normal crossroad control method, that is the fifth row. Also, this state, i.e. the eighth row of the table, has the lowest average travel time among all 8 implemented scenarios, and in this respect, it is the best implemented scenario and can reduce the average travel time by 29 percent compared to the normal state, i.e. the first row.

- Finally, by comparing the first and fifth, second and sixth, third and seventh, fourth and eighth rows and comparing the first four methods together and the second four methods together, it is concluded that the minimum average effect of the mobile agents routing using traffic information to reduce average travel time is less than correct control of crossroads using smart traffic lights.

4. Conclusion

The main objectives of this research including: agent-based modeling of an ITS system with some of its main components such as vehicles and traffic lights as intelligent agents to help them make decisions in the simulated urban environment using different scenarios, the evaluation of the effect of these scenarios in reducing the average travel time and testing the possibility of information exchange between the components of this space, with the evaluation of the impact of this interaction. In this model, all three types of vehicle agents, traffic lights and the main agent as the center of traffic control and data collection of ITS system can communicate with each other and exchange data. By defining some criteria, the impact of such information communications and the various methods based on these communications are measured.

Here are some of the main experiences and conclusions obtained from this research. In this study, various scenarios were investigated assuming the access of vehicles and traffic lights as model agents to the current traffic information using the information of the traffic control center and interaction with it. The results showed that by considering appropriate methods in controlling traffic lights and providing drivers with access to accurate instantaneous traffic, the average travel time in the urban transport network can be significantly reduced, as the best result of the study showed a 29 percent reduction in average travel time in one scenario. Indeed, in the real world this can be somewhat different. According to the agent-based modeling done in this research, it can be said that agent-based modeling as one of the basic component based modeling methods has a high capability in modeling the complex outside world, including the dynamic and complex urban world and its traffic. In such a model, it is possible to see live and direct agents, such as cars and traffic lights, their performance, communications, and so on. It is possible to define different scenarios and test them in this system. It is worth to mention that the conditions are different in different cities and issues such as fuel prices, communication infrastructure and driving culture of people in different cities of the world or even a country should be taken into consideration. The urban transportation network cannot be simply modeled in a Raster space. Using the JADE platform and software was somehow difficult. In contrast, this software provides the modeling possibility of urban traffic in a vector space and the system can also be developed considerably.

In the continuation of this research, it can be said that we can develop the system in many aspects. In this research, agent and environment modeling was performed in a simple and uncomplicated way. For example, the streets are considered straight and without curvature, or the square is not considered in the environment, which can be considered in further studies for more accurate results. Also, in the scenarios of crossroad control by the traffic light agent, we can use a combination of two or some methods but they require powerful information processing.

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