Preprint submitted to the International Journal of Intelligent Transportation Systems Research (Springer). You can find the published version at: https://trebuchet.public.springernature.app/get_content/acb96f78-6b10-4ae1-b423-ff8ee5023cf1

CATMI: Context-Aware Traffic Management at Autonomous Un-Signalized Intersections

Hamed Vahdat-Nejad [1], Tahereh Mohammadi[2] , and Wathiq Mansoor[3]

[1] PerLAB, Faculty of Electrical and Computer Engineering, University of Birjand, Birjand, Iran
[2] Computer Engineering Department, Azad University of Birjand, Birjand, Iran
[3] College of Engineering and Information Technology, University of Dubai, Dubai, UAE

Corresponding author: H. Vahdat-Nejad (vahdatnejad@birjand.ac.ir).

ABSTRACT Intersections form a significant part of an urban area and are the nuclei of congestion. In this regard, traffic management in un-signalized intersections is a considerable challenge because the unorganized passage of vehicles may lead to accidents, traffic jams, or even deadlocks. This can also increase the average waiting time of vehicles. In this research, a context-aware mechanism (CATMI) is proposed to calculate the priority of vehicles for passing the intersection. To this end, multi-attribute decision-making is utilized, which obtains a formula based on the effectiveness of the contributed contextual elements. Based on the priority, a vehicle is either granted or denied to cross the intersection. In this scheme, traffic management is accomplished such that deadlocks and starvations are prevented. The simulation result of the CATMI mechanism is compared with the results of previous traffic control systems. The results indicate that at intersections with various input rates, CATMI reduces the delay in most scenarios.

Keywords- Traffic control, Un-signalized intersections, Vehicle sensor, Vehicular Ad-Hoc Network

I. INTRODUCTION

Recent advancements in the vehicle industry have provided the design and implementation of the Vehicular Ad Hoc Network (VANET) [1]. VANET is a specific term used for describing the self-organizing ad hoc network of moving vehicles [2]. It employs new information processing technologies such as pervasive computing, context awareness, and cloud computing at the application layer to meet transportation needs and provide high-level services [3]. In context-aware VANETs, vehicles can share diverse contextual information with one another and with the infrastructure [4]. In such networks, any information that describes driving situations (such as location, speed, and acceleration of the vehicle, traffic information, weather conditions, etc.) is called driving context [5].

Today, the evolution of new technologies allows for the imagination of new traffic management solutions [6, 7]. Intersections constitute an essential part of the urban network and are sources of congestion that influence the continuity of traffic flow. In this regard, the control of un-signalized intersections is a major challenge for traffic management because the flow of vehicles, regardless of the rules imposed by a traffic light, may lead to accidents or deadlocks as well as traffic jams. In fact, the average traffic of un-signalized intersections is low so that the traffic light imposes unnecessary delay to the vehicles. However, occasionally increase in traffic might lead to an excessive waiting time or even deadlock.

The initial classic traffic management research at un-signalized intersections started in the previous century [8]. After the evolution of VANETS, new studies mainly have focused on autonomous vehicles that make use of vehicle-to-vehicle and vehicle-to-infrastructure communications [9]. The main objective is to increase the effectiveness of intersections by reducing delay time and avoiding collisions around intersections. Previously, it has been shown that autonomous cooperative vehicles provide better performances because of the gaining gap of time as well as time headway [10], [11], [12]. This is because the vehicles have much better cooperation and coordination in autonomous systems than human-driving vehicles. Therefore, the level of gap acceptance in conflicting lanes and the level of time headway in a single lane are reduced [13].

The preliminary studies have primarily focused on reserve-based protocols, but recent studies focus on sequence-based protocols. In the reserve-based protocols, a vehicle has to cross the lane that has been reserved by the intersection manager within the declared time [14], [10], [15]. However, this can only be done by autonomous vehicles that are equipped with advanced equipment as a violation of the cross-lane limit may result in irreversible risks. Hence, most studies have recently focused on sequence-based protocols with realistic assumptions. In these protocols, no spatial-time route is reserved for vehicles. Alternatively, before the entrance of vehicles to the intersection, they are sequenced, and the confirmation or rejection of passage is announced to them [14], [10], [15]. This decision is made based on a set of parameters. A comprehensive set of relevant parameters could result in effective traffic management. In this regard, the current research attempts to use factors influencing the effectiveness of intersections, including traffic congestion of the streets ending to the intersection, waiting time of vehicles, and traffic regulations (including the priority of vehicles in the straight direction, and left and right turns). The aim is to reduce the average delay and prevent deadlocks, starvations, and collisions. To this end, a Context-Aware Traffic Management mechanism at un-signalized Intersections (CATMI) is proposed, which is a sequence-based method for autonomous vehicles. It calculates vehicles' priority by receiving their primary context (e.g., location and speed) and deducting the secondary context information (e.g., vehicle arrival time to the intersection, vehicle priority right, vehicle waiting time, and traffic on any street ending the intersection). The CATMI mechanism leverages *Analytic Hierarchy Process* (AHP) to propose a formula for calculating the priority of vehicles. It is obtained using multi-attribute decision-making based on the effectiveness of any context element that contributes to the reduction of average delay. Finally, vehicles are processed based on their priorities to determine the confirmation or rejection of crossing the intersection.

Simulation results of the CATMI mechanism are compared with the results of previous traffic control systems. The comparison indicates that at intersections with varying input rates, CATMI considerably reduces the average delay. It also manages vehicles flow in such a way that prevents deadlocks, starvations, and collisions.

The main contributions of CATMI are as follows:

- It uses the full potential of context-awareness to accurately model the situation to a multi-attribute decision-making problem and uses AHP to solve it.
- It significantly decreases the mean waiting time of vehicles compared with previous research.

The rest of this paper is organized as follows. Section 2 presents a review of previous research. In section 3, the proposed mechanism is generally introduced, and context acquisition is elaborated. Section 4 describes the proposed vehicles sequencing scheme. Section 5 presents the simulation setup and the results, and finally, section 6 provides the conclusion.

II. RELATED WORK

Management of vehicles at intersections is an essential branch of the Intelligent Transportation System (ITS). Most of the studies in this area are focused on signal-controlled intersections. For example, the “Adaptive control system” is a traditional traffic management system that provides an algorithm for optimization of the traffic signals timing [16]. Similarly, in Webster’s control system, Webster’s well-known formula [17] is used to calculate the period and duration of the green signal [18]. Besides, Little’s control system also provides an algorithm for traffic signals timing based on Little’s formula [19].

Control of light-free (un-signalized) intersections is a significant challenge because it can cause accidents, deadlocks, or traffic jams. In general, two classes of protocols are available for traffic management in un-signalized intersections: reserve-based and sequence-based.

A. RESERVE-BASED PROTOCOLS

Reserve-based protocols are based on the time-spatial reservation. The idea of reserve-based protocols was initially proposed by Kurt Dresner and Peter Stone [20] with a multiagent reserve-based system for reducing traffic congestion at intersections and optimal passage of autonomous vehicles. Autonomous vehicles are controlled by a central computer. The proposed mechanism is centralized and includes two classes of agents: driver agents (which control the vehicles) and the intersection management agent (which is responsible for traffic management at the intersection). The intersection control policy is First-Come-First-Served (FCFS). The reservation system allows the driving agent to “call ahead” and reserve the time-slot blocks that it needs. To this end, the intersection is partitioned into an n×n grid of slots, each of which can be reserved by only one vehicle in each time step. This project is based on a restrictive assumption that no vehicle is granted the left or right turn permission, and vehicles are not allowed to change their speed while crossing the intersection [20]. In fact, the intersection management of this preliminary work did not apply to realistic scenarios. Later on, Dresner and Stone added flexibility to the mechanism by granting the left and right turns as well as speed and acceleration changes [21] [22]. Subsequently, Middlesworth and Dresner [23] have developed a decentralized mechanism specifically for autonomous vehicles in low-traffic intersections. In this mechanism, every vehicle agent regularly broadcasts a claim message to all vehicles in order to reserve a specific time-spatial slot in the intersection. Whenever a vehicle agent wants to release a reserved time-spatial slot, it sends a cancel message to all entities. This scheme leads to numerous released messages that could cause concurrency issues.

The FCFS policy has been developed by Minjie Zhu [24] into the look-ahead intersection control policy (LICP). The main idea is to select an efficient decision to allocate the crossing permission based on two criteria. The first criterion is the predicted total delay in postponing the reserve claim, while the second criterion is the predicted total delay in confirming the reserve request. This policy investigates different permission allocation modes and confirms the mode with the lowest total delay of passing regardless of the order of the claims. The main drawback of their policy is that it might result in starvation in several situations. Subsequently, Vasirani and Ossowski [25] have investigated vehicle to vehicle communication and coordination to evaluate the effect of arrival rate on Dresner's “First Come First Served” policy. They show that the proposed coordination policy is not helpful for low and high traffic congestion situations, but it reduces travel time by 6.84% for moderate traffic congestion [25].

Luis Conde Bento et al. [26] [27] have developed the Intelligent Traffic Management System (ITMS), which has an agent-oriented architecture. The infrastructure agent receives the information sent by a vehicle and transmits it to all vehicles in the area. Besides, the infrastructure agent is responsible for computing a speed profile for each vehicle, which is transmitted to the vehicle agent. The vehicle agent drives the vehicle based on the received speed profile. In a centralized autonomous system, the intersection manager receives and evaluates the movement mode of the vehicle to determine whether it has an overlap with previous modes. If necessary, the manager shifts the time, reserves the movement mode for the vehicle, and announces the reserved mode to the vehicle [28]. Finally, the heuristic approach proposes a three-level reserve-based heuristic algorithm for vehicle scheduling in the intersection [29].

In summary, reserve-based mechanisms for traffic management at un-signalized intersections are based on some realistic assumptions that enforce vehicles to cross from a specific lane, at a specific time, and with a specific speed.

B. SEQUENCE-BASED PROTOCOLS

In sequence-based protocols, no reservation is made, and instead, a sequence is specified for the passage of vehicles. This protocol handles the failures of crossing much better than reserve-based protocols. The application of sequence-based protocols to traffic management at intersections started in 2010 when Wu et al. [30] have proposed “contextualized traffic control” in an intersection. It manages traffic at intersections by sequencing the passage of vehicles based on the “First In First Out” (FIFO) policy. This centralized mechanism conforms to the vehicle scheduling idea, which considers the intersection as a critical resource shared by vehicles [30]. Although this sequencing policy for traffic management is straightforward, it can lead to high waiting times in various scenarios.

“Transparent Intersection Management” [14] [10] [15] is a sequence-based protocol for managing the access of cooperative autonomous vehicles to intersections based on the FIFO policy. It uses vehicles' position, velocity, and acceleration and exploits Petri nets to model the traffic behavior at intersections. Based on the modeling results, a platoon-based control strategy [31] has been proposed, which tries to avoid mode switching between interfering vehicles. In other words, it avoids cutting the movement sequence of the vehicles inside a platoon as much as possible. Although this scheme could decrease the mean waiting time of vehicles, it could result in starvation for the vehicles entering from a secluded street. Finally, Yan et al. have investigated the passage of autonomous vehicles from intersections as a scheduling problem in which all vehicles are modeled as jobs. In a traditional scheduling problem, several jobs (or tasks) should be scheduled sequentially to be served by the processor. In this mapping, serving a job is regarded as crossing a vehicle from the intersection. The most critical data elements used in the scheduling algorithm are vehicle arrival time at the intersection, and the time each vehicle requires to get through [32]. As the scheduling problem is NP-hard, the execution of this scheme might require massive computational needs and much processing time for a large number of vehicles.

In this paper, a context-aware intersection management scheme is proposed to reduce the average delay of vehicles. Because context-awareness is a solution for dynamic environments and context has a dynamic nature [33], we expect the proposed scheme to address the issue appropriately.

III. CATMI: Context acquisition

CATMI is a Context-Aware Traffic management system for un-signalized Intersections, aiming to reduce the average delay of autonomous vehicles and prevent deadlock, starvation, and collision. CATMI is based on several contextual information, easily obtained from vehicles and the intersection controller. Therefore, it could be applied to any un-signalized intersection. CATMI uses a sequence-based mechanism, the architecture of which is depicted in Figure 1. The functionality of CATMI consists of two general steps. At first, CATMI acquires the required contextual information. Subsequently, upon this information, it periodically calculates the current priority of each vehicle and sorts them accordingly (sequencing). Context acquisition is discussed in this section, and then the following section describes the sequencing procedure.

Extracting primary context: When a vehicle enters the control range of the intersection manager, it sends a claim message that contains the required contextual information (including the vehicle speed, acceleration, position, and direction, as well as time of arrival at the control range) to the intersection manager. Vehicle speed and acceleration are collected using the speedometer and accelerometer sensors embedded in the vehicle. The vehicle's position and direction are determined using the Global Positioning System (GPS), whereas the exit street is extracted from the destination.

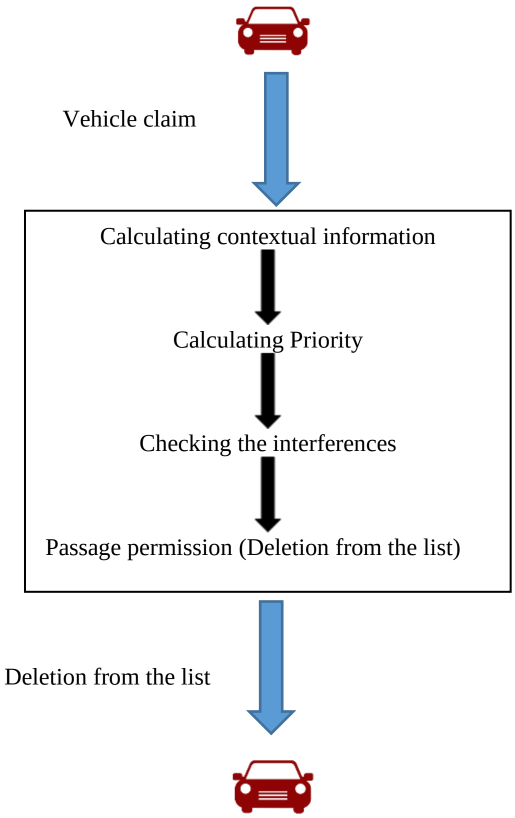


FIGURE 1. Overview of the proposed mechanism

Extracting secondary context: After receiving the vehicle claim, the intersection manager calculates the following secondary contextual information and stores the request (claim) in a list (array). The secondary context elements are as follows:

Movement flow of the vehicle: It is determined according to Figure 2 using the contextual information of the position and direction of the vehicle;

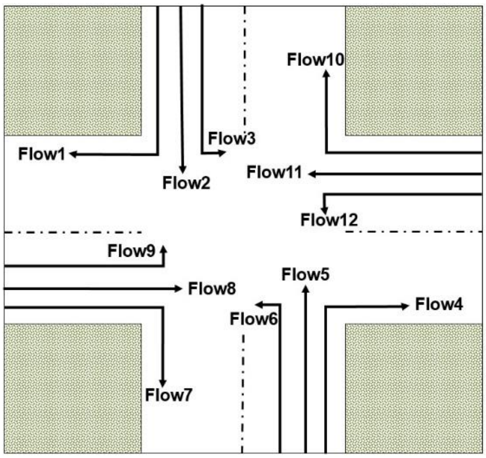


FIGURE 2. Movement flows of the vehicles

Arrival time to the intersection: It is calculated using physics' laws of motion and contextual information of the speed, arrival time of the vehicle to the control area, and control radius of the intersection.

$$T_a = CR/Speed + T_e; \qquad (1)$$

Where T_a is the expected arrival time at the intersection, CR is the control radius, and T_e denotes the time of the vehicle's entrance to the control area.

Crossing distance of the vehicle inside the intersection: In order to calculate the time required by the vehicle to traverse the intersection, it is necessary to calculate the distance traveled by the vehicle. Vehicles travel different distances depending on the movement path and width of streets. In the following, the relation for calculating this passage distance is described based on the vehicles' movement path category.

Right turn: The distance is equal to one-fourth of the perimeter of a circle centered on the right corner of the intersection in relation to the vehicle. In other words, as seen in Figure 3a, for a vehicle with Flow 1, the center of the circle is Point I, and its radius is denoted by R. Therefore, the distance traveled by the vehicle is $1/4(2\pi R)=1/2\pi R$. For simplicity, it is assumed that the point of entrance of the vehicle to the intersection is at the center of the entrance street. Hence, the required radius is assumed to be half of the width of the entrance street. In the future, it would be possible to use the entrance coordinate of the vehicle (which can be obtained from the GPS embedded in the vehicle) to calculate the radius. The traveled distance within the intersection is calculated similarly for all similar flows (flows 4, 7, and 10).

- Straight direction: The distance traveled by a vehicle to directly cross the intersection is equal to the sum of widths of two streets ending to the intersection on the right side of the vehicle. As seen in Figure 3b, the distance for the straight direction in Flow 2 is equal to 2d. For similar flows (flows 5, 8, 11), the distance is calculated similarly.
- Left turn: in this case, the distance is equal to one-fourth of the perimeter of a circle with its center on the left corner of the intersection in relation to the vehicle. As seen in Figure 3c, for a vehicle with Flow 3, the circle's center is Point I, and its radius is denoted by R. Hence, the distance is equal to $1/4(2\pi R)=1/2\pi R$. For simplicity, it is assumed that the point of entrance of the vehicle to the intersection is at the center of the entrance street. Therefore, the required radius is equal to 1.5 times the entrance street's width. It is also possible to calculate the required radius based on the entrance coordinate of the vehicle. For all similar flows (flows 6, 9, and 12), the distance traveled within the intersection is calculated in the same way.

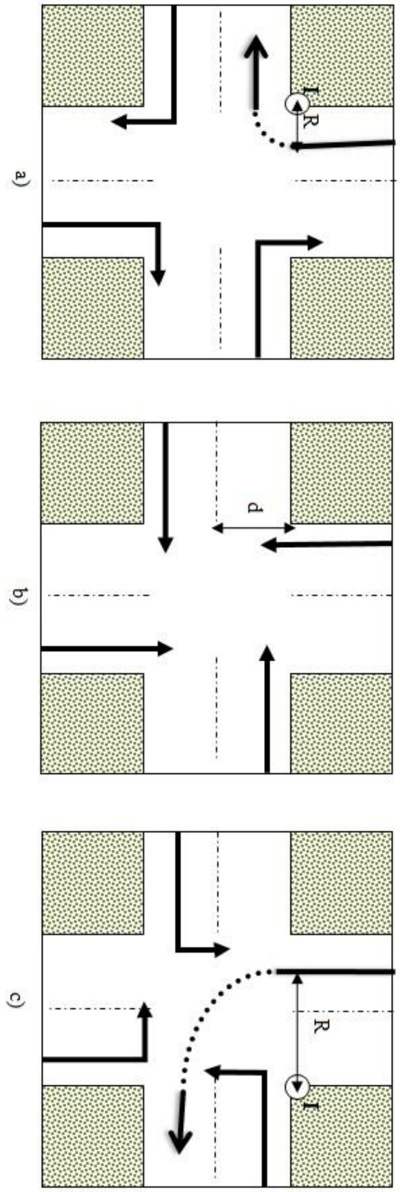


FIGURE 3. Travelled distance for: (a) Flow 1; (b) Flow 2; (c) Flow 3

Normal travel time of the vehicle: It is the time spent by the vehicle to cross the route at the same speed when there is no vehicle at the intersection. It is calculated as follows:

$$T_{normal}=T_a+ (d/Speed) \qquad (2)$$

Where T_{normal} is the expected travel time, T_a is the arrival time at the intersection, and d is the distance the vehicle travels to pass the intersection.

Traffic of any of the streets ending to the intersection: It is regarded as the number of vehicles in the control range of each street. When a vehicle enters the control range of the intersection, the number of vehicles on that entrance street increases by one. Similarly, when a vehicle exits the intersection, vehicles decrease by one. Hence, traffic of the street changes dynamically.

In fact, context elements are gathered through either sensor, user interface, inference component, or static infrastructure. Static infrastructure implies roadside servers and equipment. The inference component is a software module that deducts a high-level context element from low-level ones. Table 1 summarizes the required context elements and the methods used for collecting them.

TABLE I

REQUIRED CONTEXT ELEMENTS AND THEIR GATHERING METHOD

Context	Gathering method
Vehicle speed	Speedometer and accelerometer sensors
Vehicle position	GPS
Vehicle Direction	User Interface
Vehicle arrival time	Clock
Vehicle movement flow	Inference component
Vehicle arrival time	Inference component
Crossing distance of the vehicle inside the intersection	Inference component
Normal travel time	Inference component
Traffic of any street ending to the intersection	Inference component
The physical properties of intersection (like the width of streets ending to the intersection, speed limit at intersection)	Static infrastructure

IV. CATMI: Vehicle sequencing

The intersection control policy forms the core of traffic management at intersections. When a vehicle enters an intersection's control range, it could reach the intersection within a short time, depending on the control range's length. In this research, we set the control range to 200 meters. We assume that a vehicle could reach the intersection at least after T seconds considering the maximum speed limit. When a vehicle enters the intersection's control range, it is inserted into the intersection's control policy list (array) for processing and allocation of the passage permission. The control policy is re-applied every second if the array is not empty. The control policy includes the following components: calculating the priority of vehicles, sorting the control policy array, checking interferences, and allocating/rejecting the passage permission. They are explained subsequently.

A. CALCULATING THE PRIORITY OF VEHICLES

In most of the existing control policies/algorithms, the first vehicle that enters the control range of the intersection is processed and served, regardless of the parameters influencing the priority of the vehicle. In other words, if the vehicle does not interfere with other vehicles, it obtains the passage permission. In the CATMI mechanism, using the multi-attribute decision making, a formula is proposed for calculating the priority of vehicles based on parameters influencing the total intersection delay. Delay in un-signalized intersections is the difference between travel times in situations where the vehicle crosses the intersection without being influenced by other vehicles and where other vehicles influence the vehicle's movement. The steps of the multi-attribute decision making procedure for calculating the priority of vehicles are as follows:
a) *Problem objective statement*: In the CATMI mechanism, the objective is to determine the priority of a vehicle. This is performed based on several minor attributes such as arrival time of the vehicle to the intersection, the priority of the vehicle entering from a main/auxiliary street, the priority of the vehicle in the straight direction or right/left turns, waiting time of the vehicle, and traffic load on each street ending to the intersection.
b) *Determining the assessment criteria*: The following attributes influence the problem objective: vehicle waiting time (T_{wait}), time of arrival at the intersection ($T_{arrival}$), entrance from the main street (S_{main}), entrance from an auxiliary street ($S_{auxiliary}$), direct movement (M_{direct}), right turn (M_{right}), left turn (M_{left}), and traffic load on the street (Traffic). All of these attributes are quantitative.
Vehicle waiting time, street traffic load, the priority of main or auxiliary streets, and priority of turns are positive attributes, which have a straight relation with the problem objective. For example, a vehicle that takes longer to receive the passage permission or enters the intersection from a street with a high traffic load gains a higher priority. In addition, only one of the attributes associated with the vehicle direction or the street type (main or auxiliary) is one in calculating the vehicle's priority. For example, if a vehicle enters from the main street and wants to turn left, then the values of S_{main} and M_{left} are one, and values of $S_{auxiliary}$, M_{direct}, and M_{right} are zero. Hence, these attributes are assumed to be positive attributes, and the priority of the vehicle grows in relation to the effectiveness and weight of these attributes.

On the other hand, the higher the negative attributes are, the lower the vehicle priority is. The vehicle's arrival time at the intersection is one of these attributes because the vehicles arriving at the intersection sooner shall obtain higher priorities.
c) *Determining the options*: The options are either predefined and only need to be decided on or are identified by investigating the problem domain and selecting the options with available relevant information. In CATMI, each vehicle is an option.

d) *Determining the method for scoring the attributes*: After determining the options and decision-making criteria, it is necessary to decide on the scoring of the attributes. Since the score of the attributes influencing the prioritization of vehicles is determined concerning one another, the pair-wise comparison matrix is used for scoring the attributes. In this method, the decision-maker uses relative preferences for each attribute to form a pair-wise comparison matrix. To fill the pair-wise comparison matrix, the 1 to 9 scale is used to determine the relative significance of each element in relation to other elements. In other words, the following ranks are assigned to the elements: when two elements are equally significant: 1; when one element is relatively preferred to the other one: 3; when one element is highly preferred to the other one: 5; when one element is extremely preferred to the other one: 7; and when one element is incredibly preferred to the other one: 9. Moreover, one of the 2, 4, 6, or 8 ranks is assigned if one element is preferred to another with a preference somewhere between the above preferences. In the pair-wise comparison matrix, row i is compared to column j. Therefore, all of the elements on the main diagonal of this matrix are one. In addition, each value below the main diagonal is the reverse of the value above the diagonal.

e) *Assessing attributes*: Now, it is time to assess the attributes in relation to one another. To this end, the rank of each indicator is determined in relation to others. Table 2 presents the ranks of attributes influencing the prioritization of vehicles in the CATMI mechanism. For setting these values, traffic regulations have been considered. For example, the drivers entering from the main street are superior to those entering from auxiliary streets. Moreover, turning right is superior to the straight direction, which is in turn superior to the left turn. To the authors' best knowledge, no previous research compares these attributes; therefore, we consulted several urban transportation experts to assess them. Afterward, the rounded mean values provided by them have been exploited as initial values. After performing the simulation, we regulate these values in the experiment stage via trial and error. It should be noted that the attributes (e.g., turning right, entering from the main street, traffic, etc.) and their compared values are general and applicable to all kinds of roads. Not any particular road has been considered in obtaining them.

TABLE II
RANKS OF ATTRIBUTES INFLUENCING THE PRIORITIZATION OF VEHICLES

	T_{wait}	$T_{arrival}$	S_{main}	$S_{auxiliary}$	M_{direct}	M_{right}	M_{left}	Traffic
T_{wait}	1	$\frac{1}{3}$	7	8	8	7	9	$\frac{1}{3}$
$T_{arrival}$	3	1	5	7	7	5	9	$\frac{1}{2}$
S_{main}	$\frac{1}{7}$	$\frac{1}{5}$	1	2	3	2	4	$\frac{1}{5}$
$S_{auxiliary}$	$\frac{1}{8}$	$\frac{1}{7}$	$\frac{1}{2}$	1	2	2	3	$\frac{1}{6}$
M_{direct}	$\frac{1}{8}$	$\frac{1}{7}$	$\frac{1}{3}$	$\frac{1}{2}$	1	$\frac{1}{2}$	2	$\frac{1}{6}$
M_{right}	$\frac{1}{7}$	$\frac{1}{5}$	$\frac{1}{2}$	$\frac{1}{2}$	2	1	2	$\frac{1}{6}$
M_{left}	$\frac{1}{9}$	$\frac{1}{9}$	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{1}{2}$	$\frac{1}{2}$	1	$\frac{1}{6}$
Traffic	3	2	5	6	6	6	6	1

After determining the significance of attributes, the pair-wise comparison matrix A is defined as follows.

$$A=\begin{bmatrix} 1 & \frac{1}{3} & 7 & 8 & 8 & 7 & 9 & \frac{1}{3} \\ 3 & 1 & 5 & 7 & 7 & 5 & 9 & \frac{1}{2} \\ \frac{1}{7} & \frac{1}{5} & 1 & 2 & 3 & 2 & 4 & \frac{1}{5} \\ \frac{1}{8} & \frac{1}{7} & \frac{1}{2} & 1 & 2 & 2 & 3 & \frac{1}{6} \\ \frac{1}{8} & \frac{1}{7} & \frac{1}{3} & \frac{1}{2} & 1 & \frac{1}{2} & 2 & \frac{1}{6} \\ \frac{1}{7} & \frac{1}{5} & \frac{1}{2} & \frac{1}{2} & 2 & 1 & 2 & \frac{1}{6} \\ \frac{1}{9} & \frac{1}{9} & \frac{1}{4} & \frac{1}{3} & \frac{1}{2} & \frac{1}{2} & 1 & \frac{1}{6} \\ 3 & 2 & 5 & 6 & 6 & 6 & 6 & 1 \end{bmatrix}$$

f) *Determining the weight of attributes*: The least square method is used in AHP to calculate the relative weights of attributes based on the assessment of the pair-wise comparison matrix. In this method, weights are calculated such that (3) is minimized. In the weight matrix (W), w_1 is the weight of attribute 1 (T_{wait}), w_2 is the weight of attribute 2 ($T_{arrival}$), w_3 is the weight of attribute 3 (S_{main}), w_4 is the weight of attribute 4 ($S_{auxiliary}$), w_5 is the weight of attribute 5 (M_{direct}), w_6 is the weight of attribute 6 (M_{right}), w_7 is the weight of attribute 7 (M_{left}) and w_8 is the weight of attribute 8 (Traffic), as follows:

$$W=\begin{bmatrix} w1 \\ w2 \\ w3 \\ w4 \\ w5 \\ w6 \\ w7 \\ w8 \end{bmatrix}$$

$$\min(z) = \sum_{i=1}^{n} \sum_{j=1}^{n} (a_{ij}w_j - w_i)^2 \quad \text{st: } \sum_{i=1}^{n} w_i = 1,\ w_i > 0 \qquad (3)$$

This is a linear programming equation with the equal signal as its restriction. This program can be solved using the Lagrange method:

$$u=f(x,y)+\lambda g(x,y)$$
$$L=\sum_{i=1}^{n} \sum_{j=1}^{n} (a_{ij}w_j-w_i)^2+2\lambda(\sum_{i=1}^{n} w_i-1)$$
$$\sum_{i=1}^{n} (a_{il}w_l-w_i)a_{il} - \sum_{j=1}^{n} (a_{lj}w_j-w_l) +\lambda =0 \quad l=1,2,\ldots n$$

$$\begin{cases} \frac{\delta f}{\delta x} + \lambda \frac{\delta g}{\delta x} = 0 \\ \frac{\delta f}{\delta y} + \lambda \frac{\delta g}{\delta y} = 0 \\ g(x,y)=0 \end{cases}$$

By solving the equations system, the weight coefficient of each attribute is obtained (Table 3).

TABLE III
WEIGHT COEFFICIENT OF ATTRIBUTES

Weight coefficient symbol	Attribute	Weight coefficient value
w_1	T_{wait}	0.1607
w_2	$T_{arrival}$	0.2748
w_3	S_{main}	0.0494
w_4	$S_{auxiliary}$	0.0391
w_5	M_{direct}	0.0364
w_6	M_{right}	0.0443
w_7	M_{left}	0.0299
w_8	Traffic	0.3653

The final formula for calculating the priority of vehicles is then obtained by multiplying each weight by the corresponding attribute. It should be noted that positive attributes are summed, and negative attributes are subtracted. Therefore, the proposed final weight calculation formula is expressed as follows:

$$W=0.1607\ Wait - 0.2748\ T_{arrival} + 0.0494\ S_{main} + 0.0391\ S_{auxiliary} + 0.0364\ M_{direct} + 0.0443\ M_{right} + 0.0299\ M_{left} + 0.3653\ Traffic \quad (4)$$

Next, we compute the inconsistency ratio for the matrix A:

$$I.R. = \frac{I.I.}{I.I.R.} = \frac{0.13}{1.4} = 0.0918$$

Where I.R. is the Inconsistency Ratio, I.I. is the Inconsistency Index, and I.I.R. is the Inconsistency Index of the Random matrix. The inconsistency ratio of matrix A is computed as 0.0918, which approves its consistency.

Vehicles of the control policy array that have previously received the passage permission, are sorted at the beginning of the array in the same order. Afterward, the vehicles without permission are sorted in descending order using the heap tree sorting algorithm based on the priority of vehicles. Consequently, the permission of no vehicle is canceled.

B. CHECKING THE INTERFERENCES AND PROVISION/ REJECTION OF PERMISSIONS

In order to examine the interferences in the movement of vehicles, at first, the flows with a type other than the vehicle's flow are extracted. Then the interference area is checked for temporal interferences.

To avoid the collision of vehicles, two types of flows are introduced: compliant and non-compliant flows. Compliant traffic flows are the flows in which not any two of them collide with one another; hence, they can be assigned the same priority. On the other hand, two non-compliant traffic flows collide. We define 12 types of flows, which are shown in Figure 2. For example, flow 1 complies with flows 2, 3, 4, 5, 7, 8, 9, 10, and 12 and does not comply with flows 6 and 11.

To check the temporal interference between a vehicle and another vehicle from a non-compliant flow, the intersection is divided into four sections, shown in Figure 4. Two vehicles with non-compliant flows do not interfere, provided that the time of the entrance of each vehicle to the interference area is not between the entrance and exit times of the other vehicle. That is to say, none of the vehicles can enter the region when the other vehicle is inside that region. Table 4 shows the interference areas for non-compliant flows.

After sorting the array, the first vehicle obtains the passage permission. Afterward, the interference between the movement of this vehicle and other vehicles of the array is checked. The next vehicle receives permission if it complies temporally/spatially with each of the previously selected vehicles (in terms of the movement direction and the time of crossing the interference area). Otherwise, the vehicle's request is rejected, and no permission is granted. Finally, all of the complying vehicles that lack any interference receive permission. After processing the array, a confirmation message is sent to the vehicles that receive the permission, and a rejection message is sent to other vehicles that fail to obtain the permission. The rejection message contains information about the declined acceleration of the vehicle; therefore, the vehicle is obligated to reduce its speed based on the announced acceleration. The declined acceleration is declared so that the vehicle stops at the intersection. For this, we have adopted -2 meter/s^2 as the decreasing acceleration from the previous work [31]. The intersection manager estimates and stores the waiting time of vehicles that have not obtained permission.

In the next iteration of executing the intersection control policy, the current speed of vehicles lacking permission is used in the processing. If the vehicle does not have any interference, it obtains the passage permission with the current speed, and the confirmation message is sent to the vehicle. Suppose the vehicle speed does not reach the minimum limit because of consecutive interferences and failures to obtain permission. In that case, the intersection manager forces the vehicle to increase its speed while entering the intersection. To this end, the proposed method adopts 2 meter/s^2 as the increasing acceleration from the previous work [31].

TABLE IV

NON-COMPLIANT FLOWS AND INTERFERENCE AREAS DEFINED AT THE INTERSECTION

Flow name	Non-compliant flow	Interference area/ Non-compliant flow/ Temporal interference
Flow1	6, 11	B/ 6, 11/ Exit time
Flow2	6, 7, 8, 9, 11, 12	B/ 6, 11/ Since entry until exit C/ 8, 9/ Since entry until exit C/ 7, 12/ Exit time
Flow3	4, 5, 6, 8, 9, 11, 12	B/ 11, 12/ Since entry until exit times D/ 5, 9/ Since entry until exit D/ 4, 8/ Exit time B, D/ 6/ Since entry to b area until exit from d area

Flow4	3, 8	D/ 3, 8/ Exit time
Flow5	3, 8, 9, 10, 11, 12	D/ 3, 8/ Since entry until exit A/ 11, 12/ Since entry until exit A/ 9, 10/ Exit time
Flow6	1, 2, 3, 8, 9, 11, 12	D/ 8, 9/ Since entry until exit B/ 2, 12/ Since entry until exit B/ 1, 11/ Exit time B, D/ Since entry to d area until exit from b area
Flow7	2, 12	C/ 2, 12/ Exit time
Flow8	2, 3, 4, 5, 6, 12	C/ 2, 12/ Since entry until exit D/ 5, 6/ Since entry until exit D/ 3, 4/ Exit time
Flow9	2, 3, 5, 6, 10, 11, 12	C/ 2, 3/ Since entry until exit A/ 6, 11/ Since entry until exit A/ 5, 10/ Exit time A, C/ 12/ Since entry to the c area until exit from the a area
Flow10	5, 9	A/ 5, 9/ Exit time
Flow11	1, 2, 3, 5, 6, 9	A/ 5, 9/ Since entry until exit B/ 2, 3/ Since entry until exit B/ 1, 6/ Exit time
Flow12	2, 3, 5, 6, 7, 8, 9	A/ 5, 6/ Since entry until exit C/ 3, 8/ Since entry until exit C/ 2, 7/ Exit time A, C/ 9/ Since entry to the a area until exit from c area

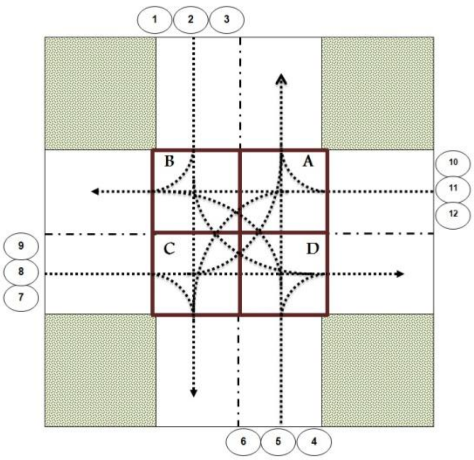


FIGURE 4. Dividing the intersections into four interference areas of A, B, C, and D

C. CALCULATION OF EXIT INFORMATION

When a vehicle leaves the intersection, it sends an exit message (to show the completion of passage) to the intersection manager. After receiving the message, the intersection manager calculates the vehicle's delay using the following formula.

$$\text{Delay} = T_{exit} - T_{normal}; \qquad (5)$$

Where T_{exit} is when the vehicle has left the intersection, and T_{normal} is the normal travel time regardless of preventive factors. The latter time is calculated using (2). Moreover, the total delay in the intersection equals the sum of delays of all vehicles that have passed the intersection. Next, the vehicle is omitted from the intersection's control policy array and inserted into another array dedicated to finished vehicles. The average delay is also obtained by dividing the total delay by the number of finished vehicles.

V. Evaluation

The Intersect-Sim simulator has been developed using the MATLAB R2013a (8.1.604) software package. The inflow of vehicles follows the Poisson process; therefore, the Poisson distribution function is used to model each entrance of vehicles into the intersection. The designed simulator is composed of two primary classes: the vehicle class and the intersection manager class. It also contains a main loop for the simulation of different stages. The vehicle class is developed to model a single vehicle along with its properties and contextual information. The intersection manager class models the properties and operations of the intersection manager and includes all of the required information about the intersection and streets ending to it (e.g., traffic load and width of each street, intersection control radius, and the information of vehicles in the intersection's control range). The main loop of the simulator consists of the following six phases based on a time vector: generation of vehicles; sensor input; insertion of a vehicle to the intersection management array; insertion of a vehicle to the intersection control policy array; and confirmation and rejection of the request for crossing the intersection. Simulations have been carried out for a four-way intersection. Table 5 shows the attributes of the vehicles and intersection. Other required characteristics of the intersection and vehicles are adopted from [31] [10].

TABLE V
ATTRIBUTES OF VEHICLES AND THE INTERSECTION

Attributes of Intersection	
Intersection Control Range	200 meter
Width of each street ending to the intersection	3.5 meter
Attributes of vehicles	
Vehicle length	5 meter
Increasing acceleration	2 meter/s^2
Decreasing acceleration	-2 meter/s^2
Maximum speed	15 meter/s

Similar to previous works, simulation has been carried out for seven input rates for each road direction (from 0.05 to 0.35 vehicle/sec), and the entrance time for vehicles has been assumed to vary from t=0 to t=1800. It should be noted that input rates below 0.05 vehicle/sec result in empty intersections, which do not impose any problem. Moreover, input rates higher than 0.35 vehicle/sec are associated with busy intersections, which require a traffic light. In each state, the simulation is repeated ten times and the average of the results is obtained and shown in Table 6.

Simulation results indicate that the average delay time increases at higher traffic loads because more vehicles enter the intersection per time unit. Moreover, in the states where the input rate is less than 0.25 vehicle/second, the average delay is very small and is almost equal to zero. However, at higher traffic loads, the average delay grows slightly.

TABLE VI
TOTAL AND AVERAGE DELAYS OF VEHICLES IN THE CATMI MECHANISM

Input rate (vehicle/s)	Number of crossing	Total delay (s)	Average delay (s)
0.05	354	9.21	0.03
0.1	729	31.91	0.04
0.15	1079	83.59	0.08
0.2	1435	165.28	0.12
0.25	1777	277.18	0.15
0.3	2141	1096.01	0.51
0.35	2467	4692.05	1.91

Afterward, the CATMI mechanism is compared with the following traffic control systems.

- Autonomous Intersection Management is a reserve-based protocol that works with the FCFS control policy [20], [23].
- Platoon-Based Traffic Control is a sequence-based protocol that minimizes the overall queue length based on the Petri nets model [31].
- Adaptive Control System is a traditional traffic control system for signalized intersections [16].
- Webster Control System applies Webster's formula to signalized intersections to calculate the green signal's duration [18].
- Little Control System works with Little's formula and obtains the length of queues and then calculates the duration of the green signal in accordance with the queue length [34].

The most important criterion for assessing the CATMI mechanism is the average delay of vehicles in crossing the intersection. Hence, it is compared with the mentioned systems regarding this criterion, and the results are shown in Figure 5. According to the results, the CATMI mechanism reduces the average delay considerably.

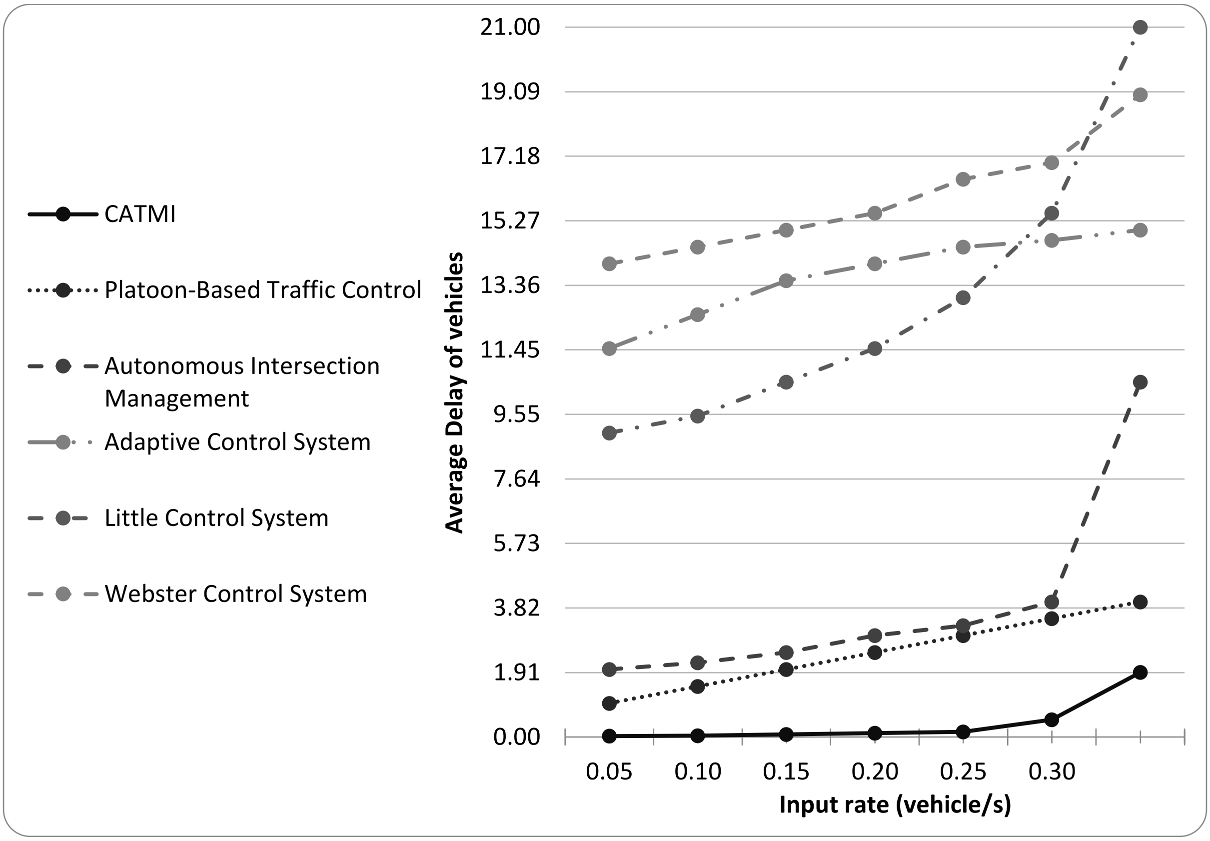


FIGURE 5. Results of comparing CATMI mechanism with other systems

The maximum input rate is assumed to be 0.35 because more crowded intersections are either square or signalized. As seen, at intersections with input rates lower than 0.35vehicle/second, by managing traffic using the un-signalized traffic control systems (such as CATMI, platoon-based traffic control, and autonomous intersection management), the average delay is considerably low. Among all these systems, CATMI achieves the least average delay. The average delay of vehicles in the Webster Control System is more than other mechanisms due to the intrinsic limitation of its proposed control policy. The duration of the green signal is updated in each period, and therefore, the mechanism fails to respond to the traffic quickly. The Little Control System performs better than the adaptive and Webster control systems at input rates less than 0.3 vehicle/second. However, with an increase in the traffic load, the average delay of vehicles escalates significantly. The average delay in the autonomous intersection management mechanism increases significantly at traffic loads higher than 0.3.

In the next phase, we compare the proposed CATMI and the heuristic approach. The heuristic approach proposes a three-level heuristic algorithm for scheduling autonomous vehicles in the intersection [29]. It has reported promising results. We perform another simulation setup with the exact scenarios of the heuristic approach [29]. This approach assumes that each road direction consists of three lanes [29], so we simulate CATMI for that intersection model. Recall that in our previous simulation model (table 6 and figure 5), each road direction has only one lane.

Besides, as yield and stop controls have been traditionally standard for un-signalized intersections, a comparison is performed with yield sign intersection, two-way stop sign intersection, and all-way stop sign intersection [35]. As all of these methods have been evaluated regarding intersection density, this parameter has been compared.

Table 8 provides the comparison results in this simulation setup in terms of average delay. To be able to compare the results, we use the intersection density parameter as defined in [29] and compared the results for the specified densities. The empty fields for yield and stop controls have not been reported [35]. However, it has been stated that for higher crowded intersections, the delay dramatically increases in these approaches [35]. As shown in table 8, the proposed CATMI approach yields much better results due to exploiting the full potential of context-awareness.

TABLE VIII
COMPARISON BETWEEN CATMI, THE HEURISTIC [29] AND YIELD AND STOP CONTROLS [35]

Intersection density (v/h)	500	1000	1500	2000	2500	3000	3500	4000	4500	5000
CATMI (seconds)	0.011	0.018	0.024	0.035	0.049	0.064	0.075	0.089	0.106	0.125
Heuristic [29] (seconds)	0.041	0.059	0.093	0.149	0.209	0.236	0.264	0.328	0.329	0.389
Yield sign [35]	NA	4.8	14	NA	NA	NA	NA	NA	NA	NA
Two-way stop sign [35]	NA	9.2	16.8	NA	NA	NA	NA	NA	NA	NA
All-way stop sign [35]	NA	15.8	43.7	NA	NA	NA	NA	NA	NA	NA

Finally, we investigate the time complexity of the proposed method. Generally, the proposed method uses four steps for handling each vehicle: acquiring contextual information, calculating the priority of the vehicle, sorting the list of vehicles, and checking the interference. Each contextual information is obtained in O(1) by executing a simple formula. Similarly, the priority of the vehicle is computed by (4) in O(1). Sorting the list of n vehicles is performed in the mean time of O(n logn), and checking the interference is accomplished in the mean time of O(n). As a result, the time complexity of the proposed method is O(n logn), where n is the number of current vehicles in the intersection proximity range. In the simulation, the proposed method is executed in milliseconds on a regular laptop, making it suitable for running on a server of the un-signalized intersections.

VI. CONCLUSION

In this paper, CATMI has been proposed to calculate the priority of vehicles for crossing an un-signalized intersection. The priority of vehicles is calculated by a formula, which has been obtained using the multi-attribute decision-making optimization method based on the effectiveness of the contributing contextual information. The processing of vehicles to determine the confirmation or rejection of their passage through the intersection is done based on their priority. It means that the vehicle with the highest priority sits on top of the processing queue. Traffic management is carried out such that it prevents deadlocks, gridlocks, and starvation. If all vehicles behave following the defined protocol, no accidents occur. On the other hand, no starvations occur because the vehicle waiting time is used as one of the factors influencing the priority of that vehicle.

Simulation results of CATMI have been compared with the results of other traffic control systems. It reveals that at intersections with varying input rates, CATMI reduces the average delay of vehicles.

One of the future research directions is to consider other types of vehicles, such as heavy vehicles. Besides, the urgency of vehicles can be considered as a context element to grant the highest priorities to the emergency vehicles (such as ambulances, firefighting trucks, and police cars). Besides, communication losses and errors (e.g. GPS error) are other issues that should be investigated. Other contextual information such as weather conditions and dryness or slipperiness of street surface can also be used as effective context elements. On the other hand, real urban environments do not solely include a single intersection, as numerous interconnected intersections form a complicated traffic network. Hence, it is recommended to extend the CATMI mechanism for traffic management in several interconnected intersections so that the intersections can conduct traffic management across the whole network through infrastructure communication. In addition to intersections, CATMI could be extended for other traffic environments such as squares.

Author Contributions

Hamed Vahdat-Nejad: Conceptualization, Methodology- Reviewing and Editing,
Tahereh Mohammadi: Methodology, Software
Wathiq Mansoor: Reviewing and Editing

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

[1] Y. Ghaemi, H. Yashar, H. El-Ocla, N. Ramesh Yadav, M .Reddy Madana, D. Kurugod Raju, V. Dhanabal, and V. Sheshadri. "Intelligent Transport System Using Time Delay-Based Multipath Routing Protocol for Vehicular Ad Hoc Networks." *Sensors,* Vol 21, no. 22, 2021, P. 7706.

[2] A. M. Vegni, M. Biagi and R. Cusani, "Smart Vehicles, Technologies and Main Applications in Vehicular Ad hoc Networks," in *Vehicular Technologies - Deployment and Applications*, 2013, pp. 3-20.

[3] H. Vahdat-Nejad, A. Ramazani, T. Mohammadi and W. Mansoor, "A survey on context-aware vehicular network applications," *Vehicular Communications,* vol. 3, pp. 43-57, 2016.

[4] S. Al-Sultan, M. M. Al-Doori, A. H. Al-Bayatti and H. Zedan, "A comprehensive survey on vehicular Ad Hoc network," *Journal of Network and Computer Applications,* vol. 37, pp. 380-392, 2014.

[5] S. Fuchs, S. Rass, B. Lamprecht and K. Kyamakya, "Context-awareness and collaborative driving for intelligent vehicles and smart roads," in *1st International Workshop on ITS for an Ubiquitous ROADS*, 2007.

[6] H. Vahdat-Nejad and A. Ramazani, "A new context-aware approach to traffic congestion estimation," in *Computer and Knowledge Engineering (ICCKE)*, Mashhad , 2014.

[7] A. Ramazani and H. Vahdat-Nejad, "CANS: context-aware traffic estimation and navigation system," *IET Intelligent Transport Systems,* vol. 11, no. 6, pp. 326 - 333, 2017.

[8] M. C. Dunne and D. J. Buckley, "Delays and capacities at unsignalised intersections," in *Australian road research board conference*, Canberra, 1972.

[9] M. Ahangar, M. Nadeem, Q. Ahmed, F. Khan, and M. Hafeez. "A survey of autonomous vehicles: Enabling communication technologies and challenges." in *Sensors* Vol 21, no. 3, 2021, P. 706.

[10] F. Perronnet, A. Abbas-Turki and A. El Moudni, "A sequenced-based protocol to manage autonomous vehicles at isolated intersections," in *16th International IEEE Conference on Intelligent Transportation Systems - (ITSC)*, 2013.

[11] Q. Lu, T. Tettamanti and I. Varga, "Impacts of autonomous vehicles on the urban fundamental diagram," in *5th International Conference on Road and Rail Infrastructure*, Croatia, 2018.

[12] J. Rios-Torres and A. A. Malikopoulos, "Impact of connected and automated vehicles on traffic flow," in *IEEE 20th International Conference on Intelligent Transportation Systems*, Yokohama, Japan, 2017.

[13] "Research on the impacts of connected and autonomous vehicles on traffic flow," Atkins Ltd, 2016.

[14] F. Perronnet, A. Abbas-Turki, J. Buisson, A. El Moudni, Z. Renan and M. Ahmane, "Cooperative intersection management: Real implementation and feasibility study of a sequence based protocol for urban applications," in *15th International IEEE Conference on Intelligent Transportation Systems (ITSC)*, 2012.

[15] F. Perronnet, A. Abbas-Turki, A. El-Moudni, J. Buisson and R. Zéo, "Cooperative Vehicle-Actuator System: A sequence-based optimal solution algorithm as tool for evaluating policies," in *International Conference on Advanced Logistics and Transport (ICALT)*, 2013.

[16] F. C. Fang and L. Elefteriadou, "Development of an Optimization Methodology for Adaptive Traffic Signal Control at Diamond Interchanges," *Journal of Transportation Engineering,* vol. 132, no. 8, pp. 629-637, 2006.

[17] F. V. Webster, Road Research Technical Paper, London: Road Research, 1958.

[18] V. Gradinescu, C. Gorgorin, R. Diaconescu, V. Cristea and L. Iftode, "Communication, Adaptive Traffic Lights Using Car-to-Car Communication," in *IEEE 65th Vehicular Technology Conference*, 2007.

[19] J. D. C. Little, "A Proof for the Queuing Formula: L = O W," *Operations Research,* vol. 9, no. 3, pp. 383-387, 1961.

[20] K. Dresner and P. Stone, "Multiagent Traffic Management: A Reservation-Based Intersection Control Mechanism," in *in The Third International Joint Conference on Autonomous Agents and Multiagent Systems*, 2004.

[21] K. Dresner and P. Stone, "Multiagent Traffic Management: An Improved Intersection Control Mechanism," in *AAMAS '05 Proceedings of the fourth international joint conference on Autonomous agents and multiagent systems*, 2005.

[22] K. Dresner and P. Stone, "Turning the Corner: Improved Intersection Control for Autonomous Vehicles," in *Intelligent Vehicles Symposium*, 2005.

[23] M. VanMiddlesworth, K. Dresner and P. Stone, "Replacing the Stop Sign: Unmanaged Intersection Control for Autonomous Vehicles," in *The Fifth Workshop on Agents in Traffic and Transportation Multiagent Systems*, 2008.

[24] M. Zhu, X. Li, H. Huang, L. Kong, M. Li and M.-Y. Wu, "LICP: A look-ahead intersection control policy with intelligent vehicles," in *MASS '09. IEEE 6th International Conference on Mobile Adhoc and Sensor Systems*, 2009.

[25] M. Vasirani and S. Ossowski, "Learning and coordination for autonomous intersection control," *Artificial Intelligence,* vol. 25, no. 3, pp. 193-216, 2011.

[26] L. C. Bento, R. Parafita and U. Nunes, "Intelligent traffic management at intersection supported by V2V and V2I communications," in *15th International IEEE Conferences onIntelligent Transportation Systems*, 2012.

27] L. C. Bento, R. Parafita and U. Nunes, "Intelligent Traffic Management at Intersections: Lagacy Mode for Vehicles not Equipped with V2V and V2I Communications," in *IEEE Conference on Intelligent Transportation Systems*, 2013.

[28] C. Wuthishuwong and A. Traechtler, "Vehicle to infrastructure based safe trajectory planning for Autonomous Intersection Management," in *13th International Conference on ITS Telecommunications (ITST)*, 2013.

[29] A. P. Chouhan and G. Banda, "Autonomous Intersection Management: A Heuristic Approach," *IEEE Access,* vol. 6, pp. 53287 - 53295, 2018.

[30] J. Wu, A. Abbas-Turki and A. Ei Moudni, "Contextualized Traffic Controlling At Isolated Urban Intersection," in *The 14th World Multi-Conference on Systemics, Cybernetics and Informatics: WMSCI*, 2010.

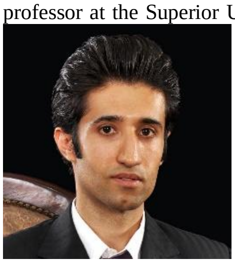
[31] J. Wu, F. Yan and A. Abbas-Turki, "Mathematical proof of effectiveness of platoon-based traffic control at intersections," in *16th International IEEE Conference on Intelligent Transportation Systems - (ITSC)*, 2013.

[32] F. Yan, J. Wu and M. Dridi, "A scheduling model and complexity proof for autonomous vehicle sequencing problem at isolated intersections," in *IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI)*, 2014.

[33] H. Vahdat-Nejad, "Context-Aware Middleware: A Review," in *Context in Computing*, P. Brézillon and A. J. Gonzalez, Eds., NewYork, Springer New York, 2014, pp. 83-96.

[34] R. Wunderlich, L. Cuibi, I. Elhanan and T. Urbanik, "A Novel Signal-Scheduling Algorithm With Quality-of-Service Provisioning for an Isolated Intersection," *Intelligent Transportation Systems,* vol. 9, no. 3, pp. 536-547, 2008.

[35] M. Yun and J. Ji, "Delay analysis of stop sign intersection and yield sign intersection based on vissim," in *13th COTA International Conference of Transportation Professionals*, Shenzhen, China, 2013.



HAMED VAHDAT-NEJAD, is currently an associate professor at the computer engineering department of the University of Birjand. He was a visiting professor at the Superior University in Lahore in the Summer of 2018 and at the Daffodil International University in Dhaka in the Summer of 2017. He received his Ph.D. from the computer engineering department of the University of Isfahan in 2012, his master's degree from the Ferdowsi University of Mashhad in 2007, and his bachelor's degree from the Sharif University of Technology in 2004. He was a research scholar with the Middleware laboratory at the Sapienza University of Rome in the 2011-2012 period. Currently, his research is focused on smart cities, intelligent transportation systems, and ubiquitous computing. He has (co)published more than 50 papers in conferences and journals, and leads the Pervasive & Cloud computing Lab at the University of Birjand. He has served as the chairman of the 1st & 2nd International Workshop on Context-aware Middleware for Ubiquitous Computing Environments, "3rd, 4th, and 5th International workshop on Pervasive and Context-aware middleware" as well as 1st conference on healthcare computing systems and technologies. He has served as TPC member for many conferences. Currently, he is an IEEE senior member and serves as an associate editor for Elsevier Computers and electrical engineering journal.