

지능형 교통 시스템을 위한 긴급 상황에서의 도로 예약 방식

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The Road Reservation Scheme in Emergency Situation for Intelligent Transportation Systems

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요 약

운송은 우리 사회에서 사람들과 화물, 정보의 이동을 제공함으로써 중요한 역할을 해왔다. 하지만 교통사고와 교통 체증, 대기 오염 등을 유발하는 부정적인 면도 가지고 있다. 이러한 문제의 주 원인은 차량 수의 급격한 증가에 있다. 이러한 문제들을 완화시키는 가장 쉬운 방법은 새로운 도로 기반 시설을 건설하는 것이지만, 시간과 비용, 공간 등과 같은 자원의 제약이 있다. 따라서 기존 도로 기반 시설을 효율적이고 안전하게 관리할 필요가 있다. 본 논문에서는 유비쿼터스 센서 네트워크를 사용한 도로에서 긴급 차량 출동을 위한 빠르고 안전한 도로 예약 방식을 제안한다. 또한 앰블런스나 소방차, 경찰차와 같은 긴급차량들이 목적지에 빠르고 안전하게 도착할 수 있도록 세 가지 예약 방법에 대한 비교분석을 하고 다양한 도로 상태에서 예약되지 않은 경우에 비해 예약을 한 경우 약 1.09 ~ 1.2 배 빠른 속도를 낼 수 있음을 시뮬레이션을 통해 보여준다. 도로 예약을 사용하는 경우 긴급차량의 속도를 줄이지 않으면서 안전하게 운행할 수 있으며, 교통 체증을 완화시키는 데도 도움을 줄 수 있음을 보인다.

Key Words : road reservation, incident management, emergency response, USN, ITS

ABSTRACT

Transportation has been playing important role in our society by providing for people, freight, and information. However, it cuts its own throat by causing car accidents, traffic congestion, and air pollution. The main cause of these problems is a noticeable growth in the number of vehicles. The easiest way to mitigate these problems is to build new road infrastructures unless resources such as time, money, and space are limited. Therefore, there is a need to manage the existing road infrastructures effectively and safely. In this paper, we propose a road reservation scheme that provides fast and safe response for emergency vehicles using ubiquitous sensor network. Our idea is to allow emergency vehicle to reserve a road on a freeway for arriving to the scene of the accident quickly and safely. We evaluate the performance by three reservation method (No, Hop, and Full) to show that emergency vehicles such as ambulances, fire trucks, or police cars can rapidly and safely reach their destination. Simulation results show that the average speed of road reservation is about 1.09 ~ 1.20 times faster than that of non-reservation at various flow rates. However, road reservation should consider the speed of the emergency vehicle and the road density of the emergency vehicle processing direction, as a result of Hop Reservation and Full Reservation performance comparison analysis. We confirm that road reservation can guarantee safe driving of emergency vehicles without reducing their speed and help to mitigate traffic congestion.

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I. Introduction

Since the twentieth century, transportation has been one of the great industries. As the indispensable element of the economy, it has been playing an important role in our society by providing mobility for people, freight, and information. While the transportation has such positive effects on our economy, it cuts its own throat by creating car accidents, traffic congestion and air pollution. The main cause of these problems is a noticeable growth in the number of vehicles. With the dramatic increase in demand for vehicles, wider road infrastructures have been built to expand the capacity of the existing road networks, but such a temporary expedient will not contribute to a functional solution for extreme traffic congestion^[20]. To solve these problems, road management and road infrastructure should be improved considering the various constraints such as time, money, and space. At this stage, ITS (Intelligent Transportation System) could be considered one of the most suitable solutions.

ITS is a composite traffic information management system that grafts information communication technology onto the components of a traffic system in order to improve the efficiency, productivity and safety of public transportation. As critical issues related to car accidents and traffic congestion are being magnified in modern societies, the ITS is gradually spotlighted as a method to deal successfully with these problems. To manage road networks effectively and safely, recent research has been investigating challenges such as safety driving and traffic congestion mitigation with various angles.

In this paper, we focus on emergency vehicle response for incident management in ITS fields so as to guarantee safe and fast driving and relieve traffic congestion. An Emergency vehicle is the general term for ambulances, fire trucks, and police cars in this paper. In the current freeway management system, although emergency vehicles heading to an accident scene have higher priorities than general vehicles in the legal aspect, they might move to the accident scene by using a shoulder on

the freeway, or by making a terrible rush ignoring the traffic signals in urban areas. Consequently, they earn demerits through taking risks of colliding with other vehicles, and taking a long time to arrive at their destinations. In order to reduce additional cost and time for rescue and guarantee the safety of emergency vehicles, our idea is to allow emergency vehicles to reserve a road on a freeway for arriving to the scene of the accident quickly and safely using ubiquitous sensor networks.

The remainder of this paper is organized as follows: The next section describes the related works. After an incident management process in the Section III, then Section VI presents an overview of our incident management along with road reservation schemes. Next, simulation results are discussed in Section V. Finally, the conclusion is given in Section VI.

II. Related Works

Generally, ITS have been recognized as an integrated tool to reduce traffic congestion and improve safety. Although ITS has fallen short of our expectations, many countries have implemented and deployed incident management systems such as STREAMS^[28] in Australia, COMPASS^[21] in Germany, CHART^[4], TranStar^[2] and TransGuide^[19] in North America, EMAS^[12] in Singapore, Hanshin Expressway^[33] in Japan, NingLian Expressway^[26] in China and so on. To accomplish incident management, they rely on different technologies such as CCTV, loop detector, radar sensors, speed sensors, ramp meters, short message service, variable message sign, travelers' advisory radio transmitters and Internet.

Moreover, there has been considerable work in vehicular sensor networks which enable vehicles to communicate with each other via Vehicle-to-Vehicle Communication (V2V) as well as with roadside base stations via Infrastructure-to-Vehicle Communication (I2V). VICS^[29] and AHS^[5] system provide road traffic information for driving safety via I2V while FleetNet^[11] and TrafficView^[23] improve the driver's safety and comfort via V2V.

Finally, our work is laying on the similar way with Lane Reservation^[24] and Active Highways^[16] for the travel time guarantee by booking travel routes based on congestion pricing concept. However, they eschew dealing with traffic accidents on the high-priority lane. It is somehow similar to the vehicle routing problem with time windows (VRPTW) in the sense that both selects the optimal route from a depart node to a destination node within a given time window^[8,17].

However, there are also differences between them. 1) While the VRPTW is to minimize the total distance traveled or the number of vehicles used, or a combination of these, our proposed road reservation is to minimize total travel time resulting from reserved lanes considering the traffic impact to unreserved lanes. 2) The VRPTW considers all vehicles to be identical, whereas our model consider them to be heterogeneous. In our model, we consider four types of vehicles: buses, cars, trucks, and emergency vehicles. 3) The biggest difference is the effect of the violation on the time constraint; the VRPTW can apply a penalty cost if the travel time limit is violated. However, the violation on the limit in case of emergency such as car accidents will cause an immeasurable loss of life. To the best of our knowledge, there has not been any published work on the performance evaluation and analysis of road reservation scheme specifically in incident management.

III. Incident Management Process

Incident management is defined as activities to reduce the duration and impact of incidents and improve the safety of motorists, crash victims and incident responders^[31]. It has already become an integral part of freeway traffic operation. In this section, we illustrate a brief overview of incident management process to understand the relationship between incidents and congestion.

3.1 Incident Management Process

Fig. 1 shows incident duration time defined as the elapsed time when a sudden incident occurs and it

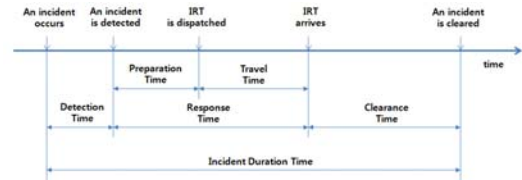


Fig. 1. Incident Management Process on a Highway

terminates^[10] at the highway for incident management process. In the Fig.1, IRT means Incident Rescue Team.

The traffic congestion due to a traffic incident will be relieved after the incident is cleared^[27]. The incident duration time is the total of detection time, response time, and clearance time. If any of the three factors can reduce the required time, the incident duration time will be shortened, resulting in reducing traffic congestion time. Considering this proposition, we propose a road reservation system using RFID-centric sensor networks to move emergency vehicles to the scene of the accident quickly and safely as well as to relieve traffic congestion by reducing response time.

3.2 Traffic Congestion

Traffic congestion is technically defined as a condition of traffic delayed because the number of vehicles trying to use the road exceeds the traffic network capacity to handle them^[14]. Traffic congestion is divided into recurring and non-recurring. The recurring congestion (non-incident-related congestion) stems from the travel demand exceeding roadway capacity, which is most common during the peak morning and evening commuting periods. This phenomenon is often called a bottleneck. The non-recurring (incident related congestion) congestion is due to incidents such as accidents, vehicle breakdowns, construction zones, bad weather and special events^[1,3]. Traffic incidents cause approximately between 50~60 percent of such traffic congestion in the roadways. Investments in traffic incident management experience a much greater benefit comparing with investments in new roadway construction. The traffic congestion may decrease road capacity, and increase the travel time^[25]. Therefore, it is reasonable that we

concentrate on reducing emergency vehicle response time as part of effort to relieve the traffic congestion caused by car accidents in this paper.

IV. Our Incident Management System

Before proceeding to our approach which provides fast and safe response for emergency vehicles by reducing response time under a road reservation scheme, it will be helpful to glance at our prior works. We designed and developed an incident management system: (i) INTRACS (Intelligent Traffic Control System) for incident detection^[32], (ii) Intelligent Bridges System based on RFID middleware for processing massive data in real time by conforming with ALE (Application Level Event) specification^[31], and (iii) IMAGES (Intelligent Multi-Agent System) which is a microscopic simulator using multi-agent concept^[30]. In this section, we will describe the road reservation scheme for fast and safe emergency response for incident management in detail after presenting a sketch of our system architecture.

4.1 System Overview

We designed a freeway incident management system using ubiquitous sensor networks. It is logically divided into low-level, mid-level, and high-level as illustrated in Fig. 2. In low-level, traffic data is basically read by RFID readers when vehicles with RFID tags move along the road. The traffic data is generated from a simulator and a test-bed, and real roads. We developed a simulator called IMAGES based on a microscopic approach using longitudinal and lateral model. The objective of IMAGES is to reflect the way real human makes decisions and performs actions in the real world on the simulator^[30]. It also has an interface to process real-time traffic data from real roads. Moreover, we implemented a small test-bed to detect accidents on the bridges^[31]. We used the IMAGES to generate traffic data in this paper.

In mid-level, traffic data generated at the low-level is collected and filtered by RFID middleware which can generate ECRports in the

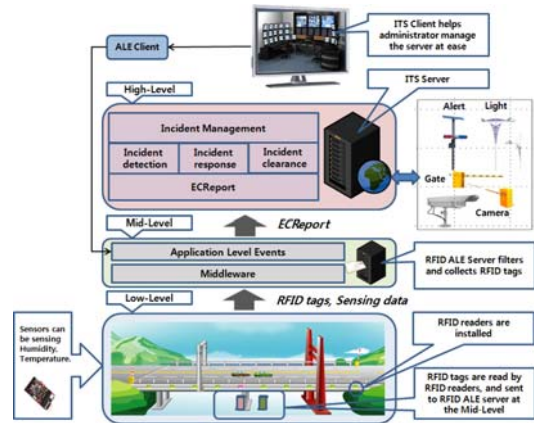


Fig. 2. System Architecture

XML format by ALE specification for the communication of the heterogeneous systems. The results (ECReports) are reported to the high-level. ALE is RFID middleware where RFID tags recognizing a reader play the role of delivering data to an application class such as EPCIS in the RFID system^[15,31].

In high-level, the ITS server processes RFID tag information and atmospheric information such as temperature, humidity and illumination and so on. The main responsibility of the server is incident management such as incident detection, incident response and incident clearance.

4.2 Road Reservation Scheme

Safer and faster evacuation related to the survival rate of the accident victims, the safety of emergency vehicles, traffic mitigation. In other words, safer and faster emergency vehicle response can dramatically improve a crash survivor's prognosis and reduce the collateral costs to society. For example, victims' chances of survival are reduced by 7-10% with every minute of delay until defibrillation with CPR (Cardiopulmonary Resuscitation)^[7]. In contrast to any other freeway crash, emergency vehicle crash has a number of unique consequences such as taking that emergency vehicle out of service, requiring other emergency vehicle response, and prolonging emergency response times^[22]. To reduce such additional costs and guarantee the maneuver of emergency vehicle against traffic congestion and car

accidents, we adopted the road reservation scheme to our incident management system.

In this part, we explore how emergency vehicles can arrive at the scene of the accident rapidly and safely using the road reservation scheme. As shown in Fig. 3, our incident management for road reservation mainly consists of four components such as roadside sensors, RFID readers, vehicle sensors, and the central server. First, roadside sensors are laid out at a regular interval around the freeway. They can communicate with passing vehicles (single hop) and with other roadside sensors (multi-hop) to gather traffic flow information and disseminate messages related to road reservation. Second, RFID readers read RFID tags of vehicles, and then send them to the roadside sensors for identifying vehicles. That is, these kinds of sensors are deployed as a communication medium for information transfer or exchange between vehicle sensors and the central server for incident management. As mentioned above, the ALE middleware provides a flexible way for management and implementation with a logical to physical mapping. It is assumed that a RFID reader represents a logical reader referring to one or more physical RFID readers which may be deployed at many places along the road considering range, transmission speed, susceptibility to environmental interferences and so on. Third, each vehicle has a tag and the sensor which can communicate with roadside sensors and other vehicle sensors. Finally, the central center (ITS server) collects traffic information from road sensors and maintains traffic statistic information such as traffic flow and density.

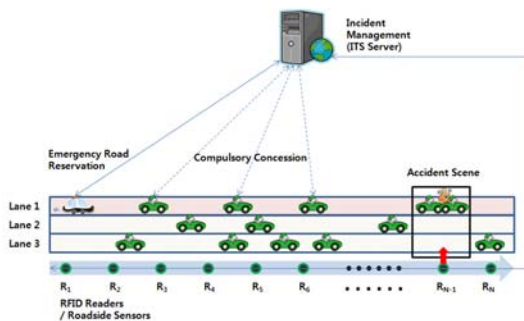


Fig. 3. Incident Management for Road Reservation

It can also track the position of a certain vehicle by identifying the vehicle.

There are two types of messages from the incident management server: (i) a reservation message for emergency vehicles to preempt the lowest density lane, and (ii) a compulsory concession message which lets other vehicles move another lane for making space for oncoming emergency vehicles. Consider the following scenario: An emergency condition does occur at the section of roadside sensor R_{N-1} in Fig.3. The incident detection module in the incident management server is executed to detect a traffic incident by analyzing the information received from roadside sensors^[31,32]. After that, the incident management server finds out the lowest density lane for emergency vehicles based on traffic statistic information, and sends other vehicles compulsory concession messages which command all other vehicles on the lowest density lane to yield to emergency vehicles with the road reservation algorithm. Consequently, emergency vehicles are allowed to reserve the dedicated path to the accident scene by receiving a reservation message from the incident management server. They can reach the accident scene (R_{N-1}) rapidly and safely by keeping the lowest density lane without experiencing speed reduction. The proposed algorithm for road reservation is based on road density and the velocity of an emergency vehicle. It enables our incident management system to book only the relevant route path for an emergency vehicle, so that the system can manage road networks efficiently and safely.

4.3 Road Reservation Algorithms

The road reservation algorithm is defined by a set of m vehicles, $V = \{V_1, V_2, \dots, V_m\}$ and a set of n road sensors, $R = \{R_1, R_2, \dots, R_n\}$. Let $I_{i,j}$ be an incident which happened at the location from R_i to R_j , where $i \leq j \leq n$. Note that a list of emergency vehicles (ER) should be registered at the central server (CS) that monitors traffic information sent from R_n . Once $I_{i,j}$ is detected and verified by the CS , the IRT will be dispatched. The road reservation algorithms follow the procedures, cf. Algorithm 1, 2,

3, and Fig. 4.

1) Request Permission ($V_m \rightarrow CS$): V_m request permission to the central server via road sensors.

2) Grant Permission ($CS \rightarrow V_m$): If V_m in ER is assigned to the IRT, the CS gives permission to V_m via road sensors.

3) Road Reservation: This procedure consists of two parts: One is to find the reservation range and calculate the lowest density lanes. The other is to reserve a lane for V_m . Each algorithm uses a different method to find the reservation range (RR) as follows:

A. *Default-Siren-Range(siren)*: The study^[6] reported that the siren is a severely limited warning device, effective only at very short ranges and very low speeds because of road noise, air conditioner, radio noise, or the soundproofing in modern vehicles. For example, no siren sound was audible in the vehicle (60km/h, no-air condition or radio) until the ambulance is within 100m. However, the effective distance could decrease to 15m in the vehicle (60km/h, air condition and radio). For simplicity, RR is set to 50m for No Reservation.

B. *Velocity-based-Range(velocity)*: The braking distance of V_m should be considered to avoid a collision. Let V_m be vehicle α and the leading vehicle of V_m be vehicle β . The total braking distance is defined as:

$$D_s = D_p + D_d, \quad D_p = v_\alpha t_p, \quad D_d = (v_\alpha^2 - v_\beta^2) / 2\mu g$$

where D_s is the total braking distance of vehicle α , D_p is the distance travelled during perception-

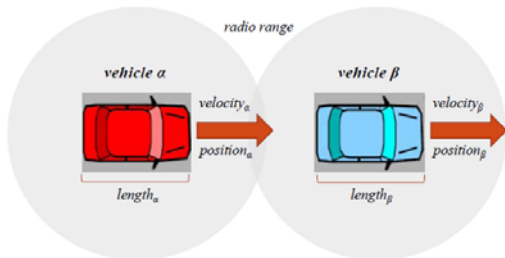


Fig. 4. An Illustration for the Road Reservation Algorithm

reaction time, D_d is the braking deceleration distance, t_p is the time for the driver in the vehicle α to perceive and react to the warning, μ is the coefficient of friction between tires and the road, and g is the acceleration of gravity. The perception-reaction time t_p is 0.5~2.5s^[9,13]. If vehicle α is travelling at 140km/h and vehicle β is at 0km/h (breakdown or incident), D_s requires about 235m. RR is equal to D_s for Hop Reservation.

C. *Destination-based-Range(start, destination)*: Simply, RR is the distance between start and destination

Algorithm 1. No Reservation for Emergency Vehicles

```

1. Request a permission
   Skip this procedure
2. Grant a permission
   Skip this procedure
3. Road Reservation ( $V_m \in ER$ )
   update = true
   DO
     1) Find the Reservation Range and the Lowest Density Lane (LDL)
       Let  $V_m$  be vehicle  $\alpha$ 
       IF update THEN
         A. Determine the Reservation Range (RR)
            $RR = \text{Default-Siren-Range}(\alpha_{\text{siren}})$ , update = true
         B. The CS calculates LDL for  $V_m$ 
           No need to calculate LDL
       ENDIF
     2) Reserve a lane
       IF ( $V_m$  has a permission) THEN
         ELSE
           Let the vehicles in front of vehicle  $\alpha$  on the same lane in RR be vehicle  $\beta$ .
            $s_a = p_\beta - p_\alpha - (l_\alpha + l_\beta)/2$ 
           IF  $s_a \geq \text{the\_desired\_minimum\_gap}$  THEN
             IF  $\|p_\alpha - p_\beta\| < RR$  THEN // RR means the range of siren
               Vehicle  $\beta$  yields to vehicle  $\alpha$  and changes into another lane
               Vehicle  $\alpha$  accelerates
             ENDIF
           ELSE
             Vehicle  $\alpha$  decelerates or tries to change the lane
           ENDIF
         ENDIF
       UNTIL ( $V_m$  arrives at  $I_{ij}$ )

```

Algorithm 2. Hop Reservation for Emergency Vehicles

```

1. Request a permission
   Request_Permission( $V_m \rightarrow CS$ )
2. Grant a permission
   IF  $V_m \in ER$  THEN
     Grant_Permission( $CS \rightarrow V_m$ )
   ENDIF
3. Road Reservation ( $V_m \in ER$ )
   update = true
   DO ( $V_m$  arrives at  $I_{ij}$ )
     1) Find the Reservation Range and the Lowest Density Lane (LDL)
       Let  $V_m$  be vehicle  $\alpha$  and the coverage range of  $R_n$  be  $d_n$ .
       IF update THEN
         A. Determine the Reservation Range (RR)
            $RR = \text{Velocity-based-Range}(\alpha_{\text{velocity}})$ , update = true
         B. The CS calculates the LDL for  $V_m$ 
            $lower = \text{argmax}_n p_n \geq R_n$ ,  $upper = \text{argmin}_n (p_n + RR) \leq R_n$ 
            $LDL = \text{argmin}_i \sum_{n=lower}^{upper} \sum_{l=1}^{LM} \frac{V_{min}}{d_n \cdot \Delta t}$ 
       ENDIF
     2) Reserve a lane
       IF ( $V_m$  has a permission) THEN
         Let the vehicles in front of vehicle  $\alpha$  on the LDL in RR be vehicle  $\beta$ .
         Vehicle  $\alpha$  moves to the LDL.
          $s_a = p_\beta - p_\alpha - (l_\alpha + l_\beta)/2$ 
         IF  $s_a \geq \text{the\_desired\_minimum\_gap}$  THEN
           IF  $\|p_\alpha - p_\beta\| > \text{radio\_range}$  THEN
             Send_Concession_Message( $CS \rightarrow \beta$ )
           ELSE
             Send_Concession_Message( $\alpha \rightarrow \beta$ )
           ENDIF
         ENDIF
         Vehicle  $\beta$  changes into another lane except the LDL
         Vehicle  $\alpha$  enforces and accelerates, on the road up to its desired speed
       ELSE
         Vehicle  $\alpha$  decelerates
       ENDIF
     UNTIL ( $V_m$  arrives at  $I_{ij}$ )

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```

Algorithm 3. Full Reservation for Emergency Vehicles

1. Request a permission
   Request_Permission( $V_m \rightarrow CS$ )
2. Grant a permission
   IF  $V_m \in ER$  THEN
     Grant_Permission( $CS \rightarrow V_m$ )
   ENDIF
3. Road Reservation ( $V_m \in ER$ )
   update := true
   DO
     1) Find the Reservation Range and the Lowest Density Lane (LDL)
       Let  $V_m$  be vehicle  $\alpha$  the coverage range of  $R_\alpha$  be  $d_\alpha$ .
       IF update THEN
         A. Determine the Reservation Range (RR)
            $RR = \text{Destination-based-Range}(\alpha_{start}, \alpha_{destination})$ ; update = false
         B. The CS calculates the LDL for  $V_m$ 
            $LDL = \text{argmin}_i \sum_{j=1}^n \sum_{k=1}^m V_{ik}^{min}$ 
       ENDIF
     2) Reserve a road
       IF ( $V_m$  has a permission) THEN
         Let the vehicles in front of vehicle  $\alpha$  on the LDL in RR be vehicle  $\beta$ .
         Vehicle  $\alpha$  moves to the LDL
          $s_\alpha = p_\beta - p_\alpha - (l_\alpha + l_\beta)/2$ 
         IF  $s_\alpha < \text{the\_desired\_minimum\_gap}$  THEN
           IF  $|p_\alpha - p_\beta| > \text{radio\_range}$  THEN
             Send_Concession_Message( $CS \rightarrow \beta$ )
           ELSE
             Send_Concession_Message( $\alpha \rightarrow \beta$ )
           ENDIF
           Vehicle  $\beta$  changes into another lane except the LDL
           Vehicle  $\alpha$  enforces and accelerates on the road up to its desired speed
         ELSE
           Vehicle  $\alpha$  decelerates
         ENDIF
       UNTIL ( $V_m$  arrives at  $l_{ij}$ )

```

(the scene of accident) for Full Reservation.

After finding the Lowest Density Lane (LDL) as shown in Algorithm 2 and 3, The CS sends a compulsory concession message to other vehicles within the reservation range. Once they receives it, they move another lane for making space for oncoming emergency vehicles. In the proposed algorithms, *the_desired_minimum_gap* means the minimum gap between vehicle α and β , and *radio_range* means signal strength range of a sensor node.

V. Simulation

5.1 Simulation Tool

IMAGES used in this paper is a freeway traffic flow simulator. We designed and developed this simulator for freeway incident management in ubiquitous sensor networks using multi agent concepts as mentioned in Section IV. The IMAGES is composed of three modules: Road Management Module, Driver-Vehicle Agent module, and GUI & Statistics module. The Road Management Module generates road, land, shoulder, and on/off ramps. This module also includes a longitudinal and lateral model for acceleration, deceleration, and lane changing^[18]. In the Driver-Vehicle Agent module, complex human driving behavior involves an agent

that consists of vehicle properties (position, speed, length, and kinds of vehicles) and driver properties (acceleration, deceleration, desired time gap, and visibility). The GUI & Statistics module displays vehicle movements as well as networks statistics representing average speed, density, and flow rates as graphs^[30].

5.2 Simulation Model

A simulation model is simply set up so as to evaluate traffic flow characteristic such as speed, time, and density by every 1,000 vehicle/hour. The simulation model has a three-lane highway section 10km long for simulating an emergency vehicle travel to an accident scene. Each experiment is conducted 10 trials per flow rate for each reservation method. The scenario is as follow: We observed the average speed and average arrival time for the emergency vehicle to arrive at the accident scene by each reservation method during 1,400 seconds as shown in Table 1. At 940 seconds, a sudden incident occurs one of three lanes, and the desired speed of an emergency vehicle is set to 140km/h. We assumed that the detection time is 160 seconds, so the emergency vehicle starts at 1,000 seconds.

Table 1. Road Reservation Methods

Type	Existence	Reservation Range
No Reservation	No	Siren-based-Range
Hop Reservation	Yes	Velocity-based-Range
Full Reservation	Yes	Destination-based-Range

5.3 Simulation Results

Fig. 5 shows the result of average speed by road reservation method. For an emergency vehicle, the average speed of Hop and Full reservation is about 1.09 ~ 1.20 times faster than that of No Reservation. The reason why the average speed of two reservation cases is displayed as 138 km/h lower than its desired speed at the initial stage is that the space between the emergency vehicle and its front vehicle is not far enough, so the emergency vehicle reduces its speed. Its desired speed is reset to 138 km/h. Through the road reservation, the front vehicle

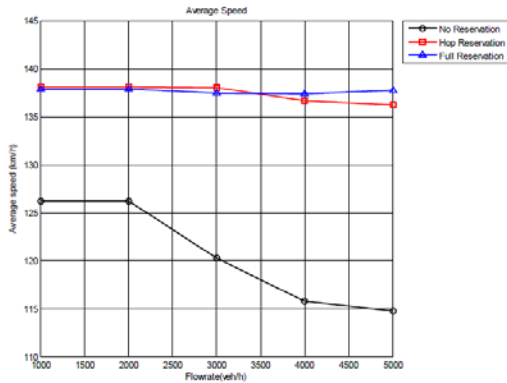


Fig. 5. Average Speed Vs. Flow rate

moves to another lane to create a sufficient space for the emergency vehicle, so it can keep its desired speed. In case of Full Reservation, it reserves the same lane as the emergency vehicle to an accident scene (destination-based), so it can maintain its speed if it is up to desired speed. However, in case of Hop Reservation, it takes into account the speed of the emergency vehicle and its front vehicle (velocity-based), so it could wait for a reservation message when the flow rate is high. In result, the emergency vehicle experiences a negligible decrease of the speed.

Fig. 6 shows the relationship between the average arrival time and flow rate. Speed is in inversely proportional to time. It is obvious that the average arrival time of non-reservation is longer than those of two reservations. Full Reservation has comparable

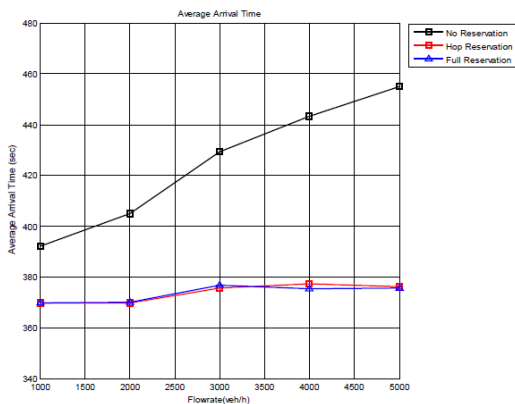


Fig. 6. Average Arrival Time Vs. Flow rate

performance to Hop Reservation with respect to the average speed and the average arrival time. It is necessary to look at the performance from the various angles. From the point of view of density by road reservation method, Hop Reservation has better performance than Full Reservation as shown in Fig. 7. In case of Full Reservation, an emergency vehicle reserves the lowest density lane even to an accident scene, and all other vehicles change their lanes to the other two lanes, resulting in high density. On the contrary, in case of Hop Reservation, an emergency vehicle reserves based on its speed, so the density is similar to No reservation.

Fig. 8 is the enlarged part of between 600 and 1,400 in Fig. 7. The Fig. 8 describes much information; when and where the accident happened and when the emergency vehicle left for the accident scene. According to the Fig. 8, the accident happened on Lane 1 at 940 seconds, and the emergency vehicle set off at 1,000 seconds. As mentioned before, an emergency vehicle reserves the lowest density lane even to an accident scene and terminates the reservation after the emergency vehicle passes in case of Full Reservation. Because Lane 1 has the lowest density, the accident happened here. The Fig. 8 shows that in case of No Reservation and Hop Reservation, each lane density is equally distributed, but not in case of Full Reservation. Although emergency vehicles requesting Full Reservation can move to the accident scene keeping their desired, the equilibrium of road

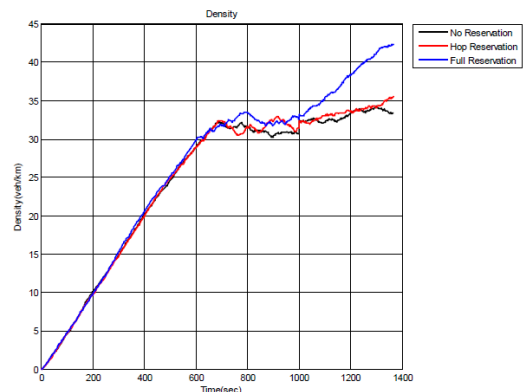


Fig. 7. Density Vs. Time (flow rate = 3,000 veh/h)

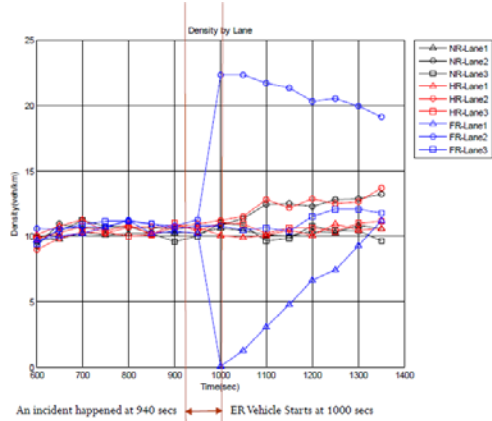


Fig. 8. Density by Lane (flow rate = 3,000 veh/h)

density can be lost.

VI. Conclusion

In this paper, we have proposed a road reservation scheme for safe and fast emergency vehicle response using ubiquitous sensor networks. In order to provide the safe maneuver for emergency vehicles and mitigate traffic congestion caused by car accidents, our incident management system allocated the dedicate path to them.

To compare No Reservation with our proposed reservations such as Hop Reservation and Full Reservation, we have evaluated the performance by three reservation method with various views; i) average speed by road reservation method with different flow rates, ii) average delay time by road reservation method with different flow rates, and iii) Density by road reservation method when the flow rate is 3,000 veh/h.

The results of our simulation demonstrated that the average speed of road reservation is about 1.09~1.20 times faster than that of non-reservation at various flow rates. However, road reservation should consider the speed of the emergency vehicle and the road density of the emergency vehicle processing direction, as a result of Hop Reservation and Full Reservation performance comparison analysis. Finally, we confirmed that road reservation can guarantee safety driving of emergency vehicles

without reducing their speed and help to mitigate traffic congestion.

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