Safe and Secure Driving for Supply and Demand Mediation type Transportation Service

Tomoichi Ebata
Center for Technology Innovation - Societal Systems Engineering
Hitachi, Ltd.
Yokohama, Japan
tomoichi.ebata.jt@hitachi.com

Masashi Imamura
Center for Technology Innovation - Societal Systems Engineering
Hitachi, Ltd.
Yokohama, Japan
masashi.imamura.zv@hitachi.com

Kei Suzuki
Center for Technology Innovation - Decarbonized Energy
Hitachi, Ltd.
Yokohama, Japan
kei.suzuki.zt@hitachi.com

Ryo Ariyoshi
Department of Civil Engineering Transportation and Urban Engineering Research Group
YOKOHAMA National University
Yokohama, Japan
ariyoshi-ryo-gd@ynu.ac.jp

Abstract*— We have studied "Supply and Demand Mediation type Transportation Service" that enables flexible and dynamic operations based on passengers real-time demands. The previous simulation of a domestic city with a population of 120,000 showed that it is possible to operate dynamic vehicle services that can decrease passenger dissatisfaction by changing vehicle routes. However, this service requires the driver to dynamically change routes according to passenger demand, which is a heavy burden on the driver. In preparation for the social implementation of this service, we tried an outdoor experiment on the campus of Yokohama National University to verify the effectiveness of this service, and in particular, to validate the solution to the above problems for the driver.

Keywords*— On-demand transportation service; Shared mobility; Mutual evaluation; Urban traffic simulation; Outdoor experiment

I. Introduction

In developed countries, the birthrate is declining and the population is aging, and it is difficult to maintain conventional public services. Therefore more flexible public services that can respond to the increasing and decreasing of the population are required. In the future, it is expected that on-demand transportation or shared mobility services will be operated flexibly and dynamically to respond immediately to the demands of passengers.

We have focused on dissatisfactions of operators, drivers, and passengers, and have studied a "demand management type transportation service" that quantifies these dissatisfactions and reflects them in the operation of public transportation services. We have simulated this service for a city of 120,000 people in Japan, and obtained the prospect that dynamic vehicle operations are possible by restricting passenger's dissatisfactions [1].

However, this service requires a direct mediation between the passenger and the vehicle operation center, while the vehicle is in motion. When the mediation is successful, the vehicle's route will suddenly need to be changed while driving. However, the driving under these conditions would be dangerous. Therefore, operations control methods that avoid the burden on the driver, would serious problems.

In order to verify the effectiveness of this service, and to validate the solution to the above problems of the driver, we tried that an outdoor experiment of a "Supply and Demand Mediation type Transportation Service based on Dissatisfaction" was conducted on the campus of Yokohama National University in February 2020.

In this paper, we describe the services, operations, and algorithms that we modified from the PC-based simulation to the outdoor experiment, and also explain the configuration of the outdoor experiment system and the newly proposed dynamic routing and its operation.

We discuss the current state of on-demand and shared mobility service and algorithms in chapter II, and outlines of our study "Supply and Demand Mediation type Transportation Service based on Dissatisfaction" in chapter III, and showed the concerns and measures about "safe and secure driving" in chapter IV. Then we explain about system configuration, service operation methods on "Yokohama National University outdoor experiment" in chapter V. After showing the experimental results in chapter VI, we present the discussion about "safe and secure driving" in chapter VII, and conclusions in chapter VIII.

II. Background

On-demand vehicle services are attracting attention from local governments in depopulated areas because they can efficiently operate vehicles through vehicle stops where there are no passengers, however the operating costs are higher than that of regular public vehicles, and many services are forced to operate at a loss.

On the other hand, in low-density areas, shared mobility concepts and on-demand transportation services have been proposed and has operated to complement or replace fixed-route transportation services[2]. The impact of shared mobility on behavior change [3][4][5] and ways to improve the convenience and passenger experience of the service [6] have been presented. For example, shared mobility has shorter waiting times and greater convenience than a taxi.

Shared mobility can be a good complement or alternative form of transportation service in underdeveloped areas and the average cost of "waiting at home" could be compared with the cost of "walking to transportation" from the passenger’s psychological viewpoints[7].

However, at this time, there are no reports that mention the dangers of dynamic routing or operation with these algorithms or outdoor experiments.

III. Supply and Demand Mediation type Transportation Service based on Dissatisfaction

A. Service outline

In a traditional "on-demand vehicle" service, (1) passenger requests are collected before the vehicle starts, (2) the best route is calculated according to the requests, and (3) the route and the departure time of each passenger are determined and notified. However, in some cases, a passenger request may be rejected when the driving time or the distance of the route are exceeded.

This service is different from the traditional "on-demand vehicle" service in that the vehicle's operating center will make a "counter-proposal" to the passenger. The "counter-proposal" will differ from the passenger's request for departure and arrival. This would result from a comprehensive review of passenger dissatisfaction, passenger dissatisfaction and company dissatisfaction.

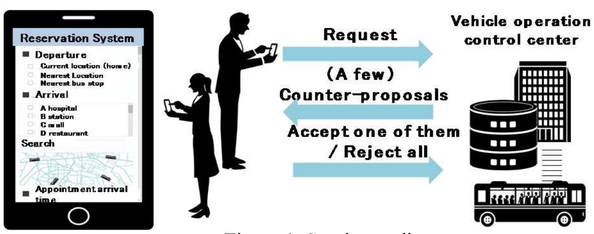

Figure 1 Service outline

In a PC-based simulation of a city of Japan with a population of 120,000, virtual passengers riding the vehicle were generated at irregular intervals, their dissatisfaction with the service was quantified, and the values were used to generate dynamic vehicle schedules and routes. Consequently, we could get the perspectives that vehicle operations are possible by limiting passenger dissatisfaction, by changing vehicle routes and diagrams dynamically.

B. Features of this service

This service will continue to mediate and dynamically modify the route, taking into account the dissatisfaction of the driver (company) and passengers. When the mediation goes in, the route of the vehicle will be changed during driving. The remaining dissatisfaction with the mediation will be provided to each passenger as "dissatisfaction points", and these points will be used in the next mediation.

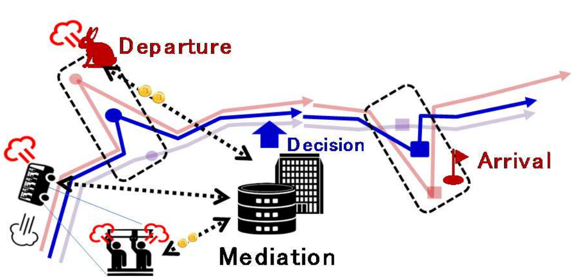

Figure 2 Changed route while driving

IV. Measures for safe and secure driving

In preparation for the social implementation of this service, we decided to conduct an outdoor experiment. However, we were concerned about some problems. One of them was safe and secures driving. At this service, the route may be changed while driving suddenly. It is difficult and risky for a driver to follow the rerouting. Prior to starting this outdoor experiment, we had discussed the following five measures from the viewpoints of "operation" and "implementation".

A. Reducing burden of driver terminal operations

The driver is required to perform the following two tasks simultaneously. (1) Driving while observing the vehicle terminal displays that are changing in real time, and (2) Supporting passengers getting in and out. Thus, the driver always would still be overloaded. Therefore we decided to employ an assistant in the passenger seat to perform all operations except for driving.

B. Shorting passenger getting in/out process

An in-vehicle system that supports passenger’s getting in/out, would delay the schedule of vehicle operation for passengers, especially if they are a beginner. As a result, the driver's driving load increased, which could have been dangerous. Therefore, we decided to skip “getting-out" operation at the getting out position, but only at the getting in position. Both the driver and the passenger could confirm the get-out position on the navigation display and their smartphone.

C. Omitting cancellation process

Depending on the situations of passenger, their requests may have to be cancelled. However, if it is possible to accept requests and cancellations during vehicle operation, it will require exclusive processing of requests, and the reservation will take much time. Furthermore, route changes would occur frequently, forcing drivers to drive in a dangerous situation. Therefore, we decided to omit the request process for cancellations and treat passengers who have not arrived at the get-in position as cancellations, and to realize fairness by forfeiting the passenger’s "dissatisfaction points".

D. Limited timing for accepting requests

This service requires a direct mediation between the passenger and the vehicle operation center, when the vehicle is moving. However, it is very burdensome for the driver to make drive in passed areas or the opposite direction of their current driving. However, if the center rejects all those requests, the advantage of real-time dynamic routing in this service would be lost.

In order for the center to give the driver to change the route, the following three conditions are required: (i) the driver must be able to recognize the route change, (ii) the driving position at that time must not interfere with the route change, and (iii) the timing of the route change must be safe and secure, regardless of the driver's experience and skills.

Therefore, the control center is designed to look like a “Route Tree” in figure 3, to move the three request areas of “prohibited request area”, “buffer area” and “permitted request area” in real time, to resolve the above three conditions.

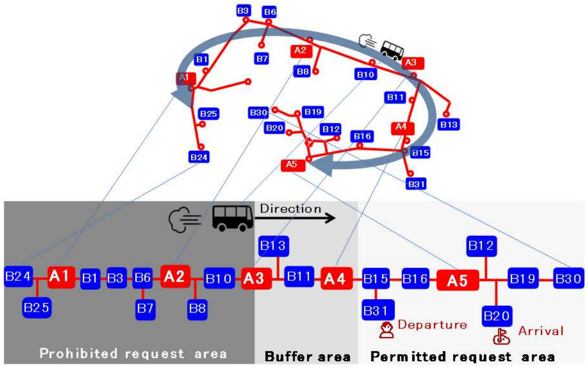

Figure 3 Route tree

E. *Routing to give drivers more discretion*

It is difficult for the vehicle operation center to collectively understand each driver's experience and skills in the above D(iii), and to set the appropriate parameters of "prohibited request area", "buffer area" and "permitted request area" for each driver. As a result, the drivers may not be able to drive with as much room in the outdoor experiment. Thus, a new routing method was needed that allows drivers to reroute with the margin.

Therefore, we developed a new routing method called "geofence routing", which indicates only the area to be passed and the order in which the driver should be passed. "Geofence" is an area surrounded by a virtual boundary (circle or rectangle), and is used to determine whether a target has entered or exited the area. The drivers may use any road as long as they pass through the area and follow the order.

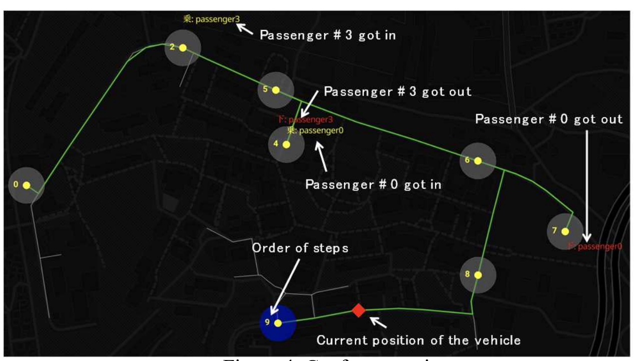

Figure 4 Geofence routing

We have implemented the following two additional functions to reduce the driver's driving load. (i) One function that could keep the vehicle operation even if the vehicle passes through the same geofence more than twice, or uses any routes in the campus. (ii) Another function was to be allowed to continue operating even if the driver skipped the geofence sequence.

In general, Geographic Information System (GIS) contains nodes and ways information [8]. However, drivers could use areas that GIS does not recognize as nodes and ways. For example, drivers can change direction in material yards, wide intersections, or parking lots.

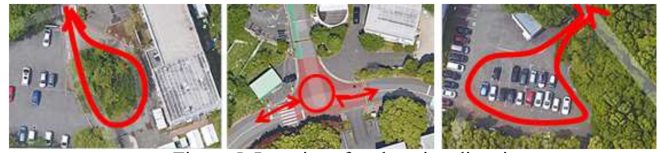

Figure 5 Locations for changing direction.

Thus, this routing has the advantage of utilizing the local geographic information of drivers.

If the routing information would be disclosed for passengers, the passengers would be able to know in advance where the moving vehicle will pass or stop, and could judge easily whether to make a request or not.

V. YOKOHAMA NATIONAL UNIVERSITY CAMPUS OUTDOOR EXPERIMENT

In this chapter, we describe the outdoor experiment of the "Supply and Demand Mediation type Transportation Service based on Dissatisfaction" on the Yokohama National University campus.

A. *Purposes of the outdoor experiment*

The purposes of this outdoor experiment are, as preparations for the social implementation of this service, to make this service system, including the vehicle operation center system, in-vehicle system, and passenger information terminals, to verify the effectiveness of this service, and to validate the solution to the above problems of the driver in chapter III.

B. *Experimental field*

This outdoor experiment was conducted on the Yokohama National University campus. The university is a Japanese national university located in Tokiwadai, Hodogaya-ward, Yokohama City, Kanagawa Prefecture, with a total area of 420,000 square meters, and has about 10,000 students and officials.

C. *System configuration for outdoor experiment*

1) *System overview*

This system consists of (i) the vehicle operation center system, (ii) the in-vehicle system, (iii) the passenger's information terminal.

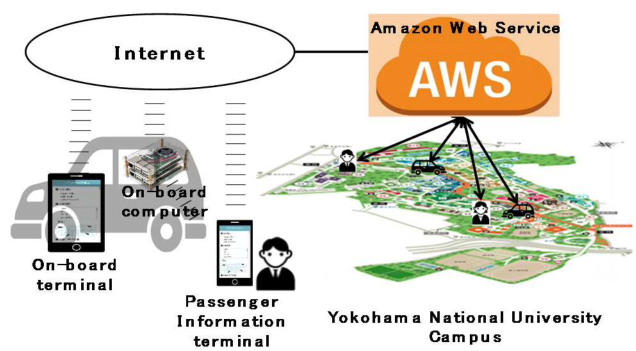

Figure 6 System configuration

2) *Vehicle operation center system*

Since this system is designed to be used by smartphones of students and officials, we adopted AWS (Amazon Web Services)® as the Internet cloud server.

3) In-vehicle systems

The in-vehicle system consists of three subsystems: (a) operation navigation system, (b)QR code display system, and (c)vehicle status display system. The figure 7 shows the system installed in the experimental vehicle for verification.

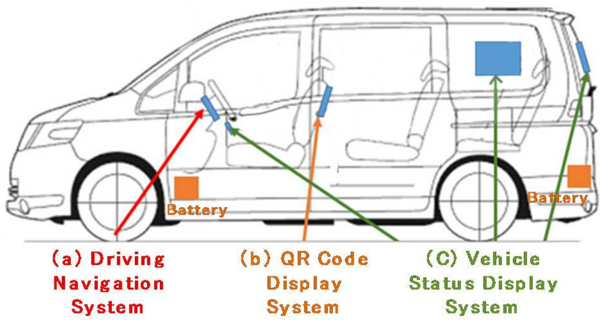

Figure 7 Experimental vehicle

a) Operation Navigation System

This system is a navigation system that provides the driver with dynamic real-time map information and driving directions provided by a server, using Apple iPad® and Bad Elf® 2300 (high-precision GPS logger).

b) QR code display system

This system confirms that passenger's getting in/out in this experimental system. The tablet displays a different QR code for each unit of operation, and the passenger can scan this code with passenger's smartphone to inform the system whether the passenger has got on or not.

Figure 8 QR code display system

c) Vehicle status display system

This system can display the operational status "standby," "waiting," and "moving" outside the experimental vehicle using the smartphone installed in the driver's seat and the tablet installed in the window of the experimental vehicle.

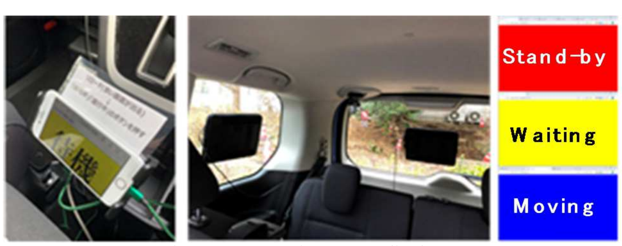

Figure 9 Operation status display system

d) On board computer

Raspberry Pi® is an in-vehicle on-board computer that provides the following functions, (i) Services for the in-vehicle systems, (ii)Wireless LAN communication in the vehicle, and (iii)Internet communication with AWS.

e) Passenger information terminals

In this outdoor experiment, the passenger terminals were their smartphone and the application was used on the web browser. The purpose of this application was to allow a number of people on campus to participate in this outdoor experiment.

D. How to use this service

After the registration of this outdoor experiment system by smartphone, the passenger could request the getting in/out locations on the map displayed on the smartphone, and they could select one route from multiple candidate routes.

The characteristics of this request method is that the control system will offer different getting in/out location the passenger requests. The passenger can choose one of the offers or reject all of them.

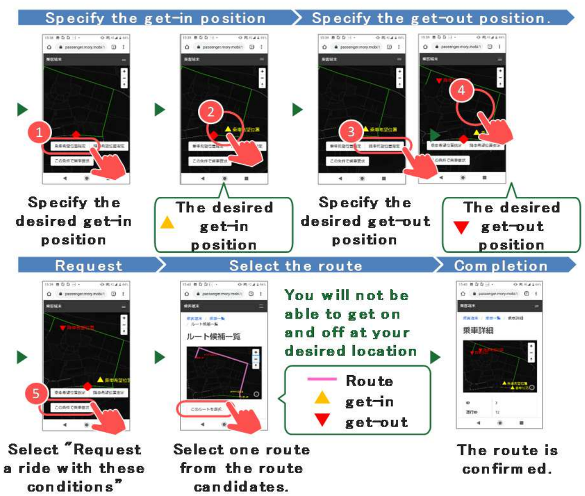

Figure 10 Requests and counter-proposals

When the passenger and the vehicle operation center system reach to the mediation, the experimental vehicle will arrive at the departure location, and the passengers will read the QR code from their smartphone and they answer a questionnaire after getting out the experimental vehicle.

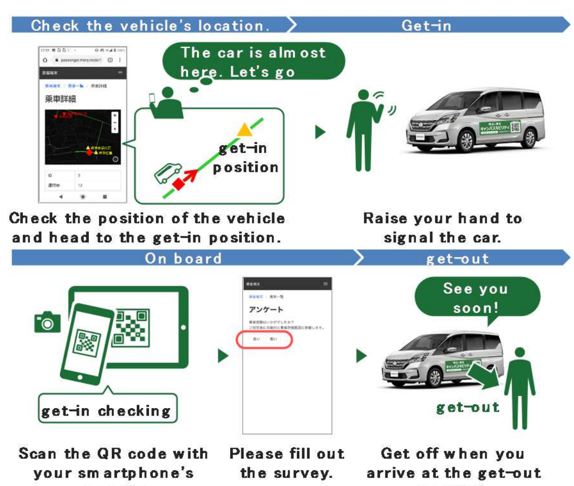

Figure 11 Usage of the service

E. *Routes and stops*

The stops on the main route are called "fixed stop (A stop)", and the stops on the route of branch lines are called "temporary stop (B stop)". In addition, these stops are not disclosed to passengers, because these stops are not to be treated like commercial bus stops. The distance between the stops should be at least 50 meters. We finally decided on the routes and stops shown in the figure 12.

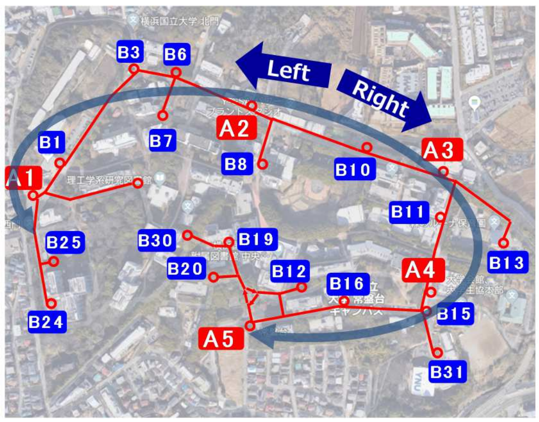

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Figure 12 Routes and stops

F. *Number of vehicles and operation schedule*

One vehicle was used for the experiment. The experimental period was 10 days from February 5, 2020, and the service period was from 10:00 to 17:00, approximately every 30 minutes. The passengers were students, officials of Yokohama National University, and the service was free of charge.

G. *Reservation Algorithm*

1) Installtion of standby reservation

Since the vehicle operation time of one-way is about 10 minutes, the handling of reservations during the “in-standby” period in figure 13, was an important problem. The reason is that prohibiting reservations during the standby period would significantly loss the opportunities to make reservations for passengers.

On the other hand, it would be extremely unreasonable to cancel a standby reservation after a later passenger makes a reservation. Therefore, during the "in-operation" period, we decided to give “first-come, first-served priority” during the "in-standby" period, and to use the same methods as in the simulation in Chapter III.

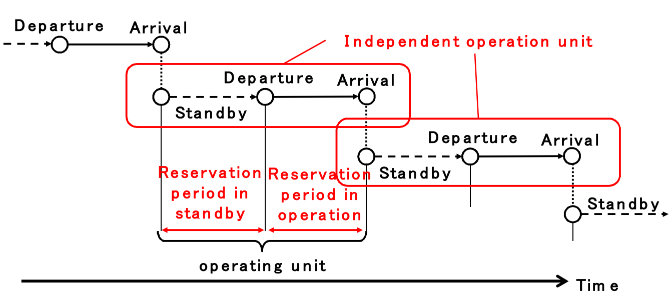

Figure 13 Reservation period in operation

2) Installation of dissatisfaction Points

In this outdoor experiment, we didn’t have to think about crowding and noise in the vehicle. Therefore, the dissatisfaction points are assigned by the results of the passenger questionnaire, and are handled as follows.

(i) If the request is not accepted during "in-standby reservation", the "dissatisfaction point" is +1. (ii) If the request is not accepted during "in-operation", the "dissatisfaction point" shall be +0. Because it is not necessary to give a dissatisfaction point to a passenger who made a reservation during "in-operation", (iii) the "dissatisfaction points" are reset to "0" when a reservation is successfully made.

VI. Experimental Results

The results of the outdoor experiment are described below.

A. *Number of operations and passengers*

(1)Total operations: 126 (=14 operations 9 days), (2) Registrant: 56 and (3) Total passengers: 107.

B. *Example of moving log*

The following figures show the moving logs, including getting in/out location and residence of the passengers.

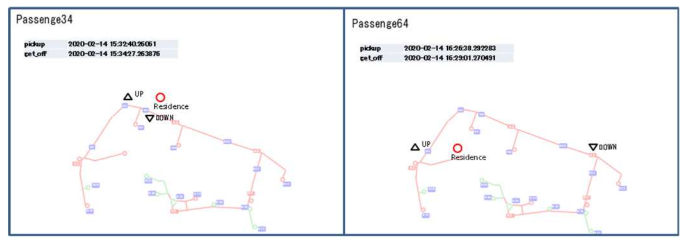

Figure 14 Getting in and out and residence log

C. *Interviews with the participants*

We interviewed passengers, drivers and their assistants, as well as those who were responsible for operations and maintenance.

1) Passengers as service users

The following comments were obtained from passengers. (i) The service was convenient because it came almost as close to the getting in locations as possible, even if the request was made far from the main route. (ii) The accuracy of the experimental vehicle's current location was high, and they were able to get in the reserved vehicle without getting lost.

2) Passengers as smartphone application users

There were following problems about passenger applications. (i) It was difficult to find their location on the map, (ii) It was annoying not to know the approximate time when the car would arrive, (iii) It is troublesome not to know the general schedule of the service, (iv) a notification system would be needed not to forget to fill out the questionnaire, (v) When people who were not affiliated with the university could not locate them on the map displayed on their smartphone,

3) Driver’s assistant

There were the following comments from the driver’s assistants. (i) All passengers’ real-time location information might be disclosed on driver’s navigation display because of picking them up easily. (ii) It might have been better to have the vehicle starts when a passenger request occurs, because of reducing empty vehicles.

4) *Persons in charge of operations and maintenance*

(i) This system was really complex, and it took much *time to* find the cause of failures. (ii) Since only a few people could fix the troubles of the systems, they had to have heavy burdens for the operation.

5) *Drivers who have duties to "safe and secure" driving*

The following were objective data and the comments based on in chapter IV.

a) *About reducing burden of driver terminal operations*

Some drivers said that they were able to concentrate on driving thanks to the driver's assistant, while others said that the operation of the terminal was not so difficult that they soon got used to it and were able to operate it by themselves.

b) *About shorting passenger getting in/out process*

This time, we decided to use the QR code display system only when getting in the vehicle, but the following problems occurred. (i)QR code authentication works differently on iPhone and Android, and sometimes did not work well. (ii) It was difficult for passengers who were not familiar with the QR codes, and the departure time of the vehicle was delayed.

c) *About omiting cancellation process*

No cancellation without notice occurred during the experiment period. Therefor we could not confirm the effect of the cancellation process.

d) *About limited timing for accepting requests*

Of the 126 total operations, all requests that could have overloaded the driver were rejected by the vehicle operation center and did not interfere with vehicle operations. There were three backtracking operations, but the distances were short and no delay occurred in this outdoor experiment.

e) *About routing to give drivers more discretion*

The skipped geofence error occurred about once a day, but did not stop the moving vehicle. Some drivers said that (i) as long as they followed the order of the geofence, they could drive the route of their choice, so they felt a relief (ii) They didn't have to mind the sequential order of geofence seriously, so they felt less pressure.

VII. DISCUSSION

A. *About "safe and secure" driving*

With regard to "safe and secure" driving which was the biggest concern for this service in this outdoor experiment, we concluded that the five measures shown in chapter IV were effective. In particular, we believe that the "geofence routing" was suitable for this service. However, some drivers said that drivers need to understand deeply the purpose and significance of "geofence routing", before starting the driving.

B. *Reflections on this experiment*

This time, we did not disclose the geofence routing to the passengers, because we thought that they would not be interested in that. However, we could have got interesting feedback from passengers, if we had disclosed it.

If we could have gotten permission from passengers and drivers, we would have tried to publish their personal information on the display of smartphone or navigation system in order to observe the behavioral changes of other passengers.

In addition, the nighttime service was abandoned for safety reasons on the campus, however we wanted to examine how passengers' request and drivers' driving would change without regular bus service at night. We also consider the expansion of this system using commercial taxies as a future challenge.

VIII. CONCLUSION

We have focused on dissatisfactions of operators, drivers, and passengers, and have studied transportation service with their dissatisfactions. However, this service requires a direct mediation between the passenger and the vehicle operation center, while the vehicle is moving. It would be difficult and risky for a driver to follow the rerouting in real time.

In order to verify the effectiveness of this service, and to validate the solution to the above problems of the driver, we tried that the outdoor experiment on the campus of Yokohama National University. After the experiment, we confirmed the operations of the system comprising this service and assured to work the service functions. In particular, we found that five measures proposed here are efficient to avoid dangerous driving

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