One Cycle of Smart Access Vehicle Service Development

Hideyuki Nakashima[1], Syoji Sano[1], Keiji Hirata[1], Yoh Shiraishi[1], Hitoshi Matsubara[1],
Ryo Kanamori[2], Hitoshi Koshiba[3,1], and Itsuki Noda[4]
[1] Future University Hakodate, Hakodate, Japan
[2] Nagoya Institute of Technology, Nagoya, Japan
[3] National Institute of Science and Technology Policy, Tokyo, Japan
[4] National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan

Abstract
Under JST RISTEX S3FIRE program, we are trying to implement Smart Access Vehicle (SAV) Service in Hakodate. The project adopts the method of service science loop - the repeated cycle of observation, design and implementation. In this paper we report the completion of its first cycle, and discuss how the cycle improved our initial design. We first conducted person trip research in Hakodate. We chose 20 candidates of various age and occupation, and recorded their everyday movements for four months. We then analyzed the result and made a person trip model. The model was then fed into our multi-agent simulator for Hakodate public transportation system. We conducted a small field test with five vehicles for one week. The most significant achievement is that we confirmed that our design of SAV system works. We succeeded in automatically dispatching five vehicles for eleven hours without any significant trouble or human supervision.
Keywords:
Smart City Hakodate, Smart Access Vehicle (SAV), Demand Responsive Transit (DRT)

1 INTRODUCTION

We initiated the project named "Smart City Hakodate" in 2009 as an envelope project, without attachment to any particular funding. Various activities followed. Future University Hakodate (FUN hereafter) signed mutual agreement on research collaboration with IBM in 2009. An NPO Smart City Hakodate was founded in 2010. FUN provided special research funding. And finally we were able to obtain JST RISTEX funding for "IT-enabled Novel Societal Service Design".

As a part of Smart City Hakodate project, we are designing and implementing a new transportation system named Smart Access Vehicle System (SAVS). The key is extensive use of information technology (IT). IT should not be regarded as just a replacement mechanism for traditional mechanical ones. Just as the invention of steam engine changed the whole societal structure, toward "industrial era" in 16th century, IT will open up a new "information era".

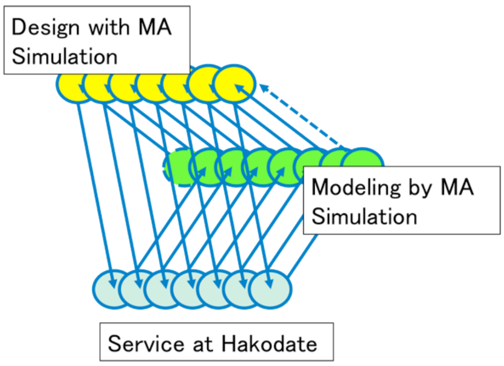

Fig. 1 Design-service loop of SAVS

Proper design is essential for IT to be effectively used in the societal system. We use the implementation methodology induced by Serviceology. We claimed that service provision essentially goes through a design-service loop [1], and our project is designed as such (Fig. 1). Although service, or field test, at Hakodate is the main process, the modeling of person trip in Hakodate and design of the algorithm for the service are also essential to the implementation of SAVS. We plan to repeat the cycle several times. The purpose of this paper is to report its first cycle taking closer look at those each steps.

2 SMART ACCESS VEHICLE SYSTEM

Smart Access Vehicle System (hereafter, we use SAV for each vehicle and SAVS for the whole system/service) is a new public transportation service that unifies bus and taxi services (Fig. 2).

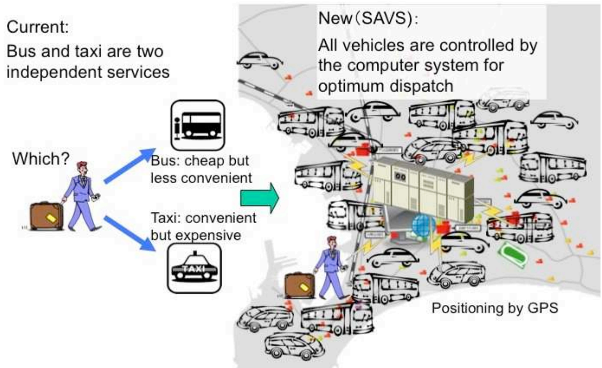

Fig. 2 The basic concept of SAVS

SAVS falls into a category called Demand Responsive Transportation (DRT) system, which is further classified into the following:

1 Detour/free stop
  Fixed route+{detour/stop} on demand
  Pre-scheduling
  Examples: many rural cities
2 Flex-routing
  Fixed stops with on-demand routing
  Pre-scheduling

Examples: EU project DRT's [2], Soja city, Todai combinicles [3]

3 Full-demand

3.1 Low demand areas (mainly pre-scheduling)

3.1.1 Full-demand bus

Example: Nakamura (Shimanto) city bus

3.1.2 Shared taxi

3.2 Urban areas (real-time scheduling)

Example: SAVS

SAVS is classified as 3.2 above, and is designed to replace current urban local public transportation systems. As far as we know of, SAVS is the only DRT designed for urban areas.

From users' point of view, the process of calling a SAV is very similar to reserving a demand bus:

1. A user contacts the system with the demand (the current location and the destination).
2. The system searches for a best vehicle considering their current position and future route.
3. The system tells the user the pickup point, the estimated time of pickup, and the estimated time to the destination (with a small margin of delay). The user has a choice to either accept or decline the service.

The differences are:

1. SAV's operate in real time (reservation is optional). A user may call a SAV when the actual demand emerges.
2. Many (in the order of 1000 or more) vehicles are involved so that the operation is efficient.

The system knows the locations and routes (destinations of passengers on board) of all vehicles. When a new demand arrives, the system searches for a vehicle that can pick up and deliver the passenger with minimum detour. Even when a vehicle is very close to the request point, it may not be selected if it is heading toward the wrong direction or if a large detour, beyond the limit of promised tie of delivery for already on-board passengers, is required. If the system cannot find any vehicle, it must decline the request. However, we are hoping that denial of service is very rare case such as a large accident or wide area disaster (including heavy storm or snow) as long as sufficient number of vehicles exist in the system.

The central dispatch system runs on MA simulation of the city traffic. If we aim for the best solution, the computation may be too heavy. We use near-optimum solution (see section 5 for more detail).

3 SAVS PROJECT AS SERVICEOLOGY

Implementation of a novel transportation system such as SAVS encounters several practical problems, which supplies several interesting issues for Serviceology.

3.1 U-Shape transition

The first issue is what we call the U-shape transition of the service. When we gradually introduce a full-demand bus system mixed with the traditional bus system, the total efficiency drops initially. Actually, after several field test of the full-demand-responsive transportation (DRT) system with a few number of vehicles, it is commonly accepted that the full-demand bus system is inefficient in high-demand areas; Full-DRT is suitable only for low-demand areas [2]. However, using MA simulation, we found that it is not necessarily the case: Full-DRT, operated fully, becomes more and more efficient as the demand increases [4]. Therefore, we have to find a practical tactics to jump over the U-shape valley.

Note: This U-Shape valley is conceptually different from the "death valley" that lies between research and industrial development. The latter is the problem of development risk, and the former is an inherent property of our proposed system. However, we believe "U-shape" problem itself is universal to most of innovational systems, since innovation is a jump.

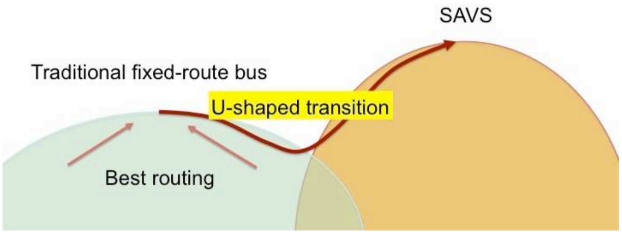

Fig. 3 U-shape Valley

3.2 Value Co-creation

Service in general should be viewed as value co-creation of the provider and the user [5]. SAVS should be a good example of value co-creation in service. Since SAVS provides the transportation infrastructure of urban life, it has a large impact on the life style of the users. Therefore, it is expected that the introduction of SAVS changes the trip pattern of people living in the area. People may give up using their private cars within the city. It will push up the importance of SAVS. It may add new value to the public transportation. Therefore, value co-created by SAVS and its users is expected to be quite large and unpredictable.

At the same time that new values are created, new requirements for public transportation may emerge. Design of SAVS should be kept changing as depicted in Fig. 1.

3.3 User Involvement

Another issue is involvement of users during the design phase (inclusive design). Since no one has ever experienced SAV system, which we regard as one implementation of full-DRT, we do not know the best service parameters. There are several parameters yet to be decided:

- the size of the vehicles (passenger capacity),
- the number of vehicles per area or per population,
- type of stops (predetermined or free),
- prior reservation,
- fare, and
- special services (such as priority delivery).

These parameters are to be decided while the service is carried out.

3.4 Law Issues

The third issue is the law restrictions. Currently in Japan, bus and taxi systems are strictly divided by the law to protect niches of each system. Taxis are not allowed to pickup multiple group of passengers (with only a few exceptions), and buses are not allowed to run free routes but have to load and/or unload passengers only at predetermined bus stops. Vehicles that carry up to 9 people are defined to be taxis and vehicles that carry more than 9 people are defined to be buses. Since our SAV system unifies both of them, it cannot be operated under the current law. We need a special designated area for SAV operation.

4 PERSON TRIP MODEL

4.1 Acquisition of person trip data

Fig. 4 is the result from our previous work [6] to show the superiority of the full-demand bus system over conventional fixed-route fixed-timetable bus systems. Horizontal axis is number of vehicles (increases proportional to population). The vertical axis is average trip time to the destination. As the population - therefore number of vehicles - increases, the average trip time decreases. Conventional bus system, plotted with "x" marks and thicker lines, becomes more efficient as the population glows - buses in large cities are more convenient than buses in rural districts. Full demand bus system is less efficient when the population is small, but quickly become more efficient than fixed route buses as the population grow larger.

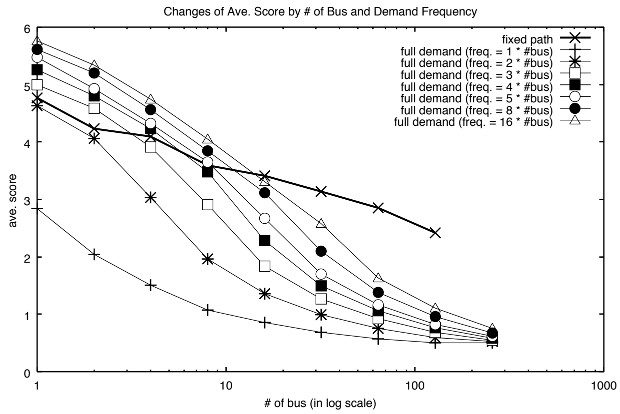

Fig. 4 Efficiency of SAVS *vs*. traditional bus [4]

However, Fig. 4 is a result of MA simulation of an artificial city, and just shows qualitative tendency. We do not know the quantitative population nor the number of vehicles of the cross point. To figure out those quantitative numbers of Hakodate, we plan to do the survey and MA simulation based on the survey.

The first step is to grasp the current status. Of course, we understand that this person trip pattern changes when the transportation system changes. Thus, this survey only supplies the initial value to our simulation.

We used two methods. (A) Direct observation of person trip using smart phones; (B) buying statistical data of mobile phone records.

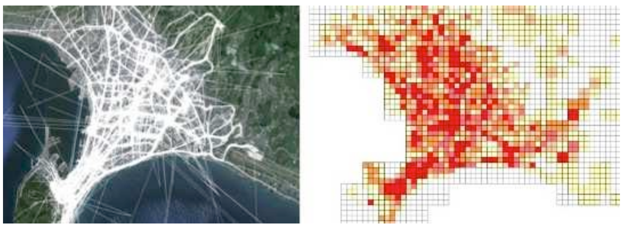

Fig. 5 Person Trip data from GPS - individual (left) and from mobile phone - mass (right)

For (A) direct observation, we developed a smart phone application to record person trip. We asked 20 people of various age and occupation to use the application for four months. As the total we gathered 2400 day*person trip records (Fig. 5 left). We also know the transportation mode (bus, taxi, private car, tram, bicycle, or on foot) and trip purpose (shopping, hospital, restaurant, work, school, or other) for each trajectory.

For (B) statistical data, we obtained OD (origin and destination) statistics. Although the mobile phone company has the trace of individual users, we could only get the statistical data for the sake of privacy protection. Fig. 5 right, for example, shows the total number of people who left the 2.5km square area within two hours of a particular date. Similar data is obtained for entering the area.

4.2 Travel mode choice model

We developed a travel mode choice model to predict travel demands. Using this model, the number of passengers for each transportation means can be estimated when an origin-destination data (section 4.1) are given.

In order to develop a travel mode choice model we introduce the *logit* model, which is one of a discrete choice model based on microeconomic utility maximization. In this model, each citizen is assumed to be a rational individual, and make a decision with attributes of the person and to attributes of the alternatives. The utility for using each travel mode (U_m), where m={private <u>car</u>, <u>pub</u>lic transportation, <u>walk</u>}, is set as follows:

$$U_{car} = V_{car} + R = ß_1\, T_{car} + ß_2\, C_{car} + ß_3 D + R,$$

$$U_{pub} = V_{pub} + R = ß_1\, T_{pub} + ß_2\, C_{pub} + ß_3 D + ß_4 + R,$$

$$U_{wlk} = V_{wlk} + R = ß_1\, T_{wlk} + ß_2\, C_{car} + ß_3 D + ß_5 + R.$$

V_m : the systematic components (fixed cost for the travel mode m),

R: the random term whose distribution is independent and identically Gumbel distributed,

T_m : travel time using mode m,

C_m : cost for using mode m,

D : the distance from origin to destination,

$ß_i$: parameters that need to be estimated from real citizen's activity pattern data

Now we can calculate the probability of using the public transport mode (*i.e.,* tram or bus) by the following formula:

$$P_{pub} = exp(V_{pub}) / (exp(V_{car}) + exp(V_{pub}) + exp(V_{wlk})).$$

Next we estimate the parameters in the logit model by a maximum likelihood method. Since the service level of each travel mode should be preset, we prepared the data of time and cost for each travel mode according to Google Map's and Yahoo's information.

Table 1 Computed parameter values for Hakodate

parameter	$ß_1$	$ß_2$	$ß_3$	$ß_4$	$ß_5$
value	-0.057	-0.133	-0.768	1.216	-0.003
t-value	-4.0	-0.3	-1.6	3.8	-0.0

The estimated parameters are shown in table 1. All parameters meet the normal sign condition even though the cost parameter ($ß_2$) does not have a statistical superiority. And the value of time calculated from our model is 42.9 JPY/min, that is an appropriate one compared with the conventional value.

Finally, we calculated the number of passengers of public transportation, using both our travel mode choice model and the total origin-destination trips calculated from the mobile phone data. The estimation results of the number of public transportation passengers are shown in the following two figures: One is the result of the number of daily passengers for a week (Fig. 6), and the other is the hourly average number of passengers in a day (Fig. 7). We can see that the number of passengers on Saturday is the maximum in a week, and the number of passengers in daytime is approximately 200 per hour.

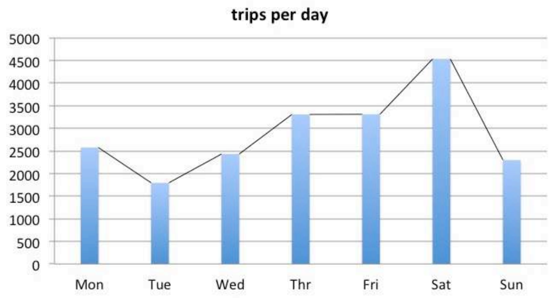

Fig. 6 Estimated trips for a week

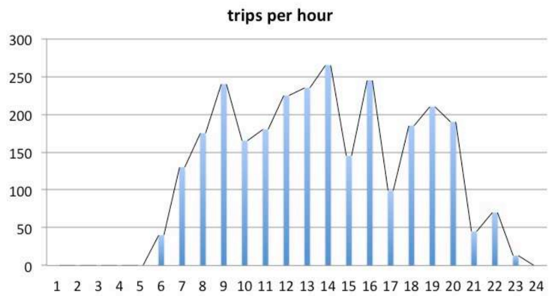

Fig. 7 Estimated trips for a day

Using those figures, we plan to run a full-scale multiagent simulation of all Hakodate (about 300K people), and compare the efficiencies of the current traffic system and SAVS. For SAVS, we will also compare the cases (1) only those using public transportation use SAVS, and (2) all transportation, including private cars, are shifted to SAVS. We are hoping to prove that SAVS is actually more efficient than traditional public transportation system using Hakodate's real data.

5 MULTIAGENT SIMULATION AND VEHICLE DISPATCH ALGORITHM

5.1 Roles of Multiagent Simulation

There are several roles for multiagent simulation. The first one is to show the efficiency of SAVS in Hakodate (as described in section 4). Another role is to design the detailed algorithm for SAVS operation. There are several unsolved issues for SAVS besides those listed in section 3.3:

- how to reflect learned data from previous operations for dispatch algorithm, and
- where to locate unoccupied cars.

These are future research issues.

5.2 Dispatch Algorithm

The system has to determine vehicle assignment (which vehicle is the best to pick up a new user) and its new route in response to demands in real-time.

In Hakodate, we have about 900 public transportation vehicles (200 buses and 700 taxis) currently. Generally, it is hard to find the optimum routing for a large number of demands, because assignment problem belongs to the class of traveling salesman problems, i.e., NP hard. Instead, we try to find semi-optimum assignment by the *successive best insertion* method [4].

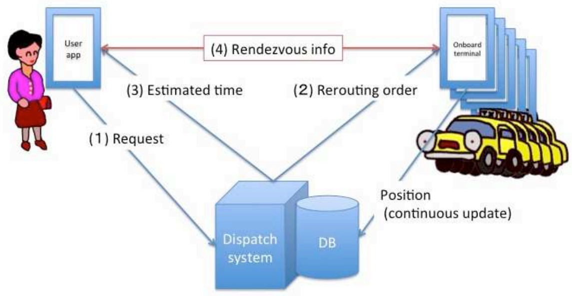

Fig. 8 Communication network of SAVS

In this method, when the request (1) arrives (Fig. 8), the Dispatch system puts each demand to an auction table in DB, where each vehicle (an agent program representing the vehicle) bets with a cost value to accept the demand. Each vehicle calculates the cost by traffic simulation based on the current holding demands and traffic situations (Fig. 9).

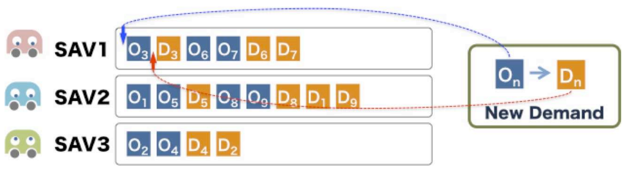

Fig. 9 Successive best insertion method used to determine vehicle assignment

This semi-optimization mechanism is simple and thus flexible enough to introduce several realistic restrictions and novel services in addition to real-time problem solving.

However, although it is a rather simple computation, yet the computational complexity is NP hard. For a large number of vehicles, in the magnitude of 1000 or more, some faster algorithm such as described in [7] is needed.

Once the best vehicle is determined, the new request is relayed to the on-board device of the vehicle (2) and estimated pick-up time is relayed to the user (3). Rendezvous information, such as locations of the vehicle and the passenger, should be displayed for both terminals (4), but this function is not implemented yet.

6 FIELD TEST

We conducted a field test in Hakodate for a week in Oct 2013. The main target is to check system's operability. We hired five taxis and about 20 volunteers (mostly students of Future University Hakodate) to randomly call vehicles. Since we had only small number of vehicles, we could not cover whole Hakodate. We limited the area of operation to inside the designated area shown in Fig. 10.

Fig. 10 Area of Oct. 2013 field test

Each passenger uses a smart phone application to request a SAV with pick-up and delivery locations on the map (with optional description of the locations). Fig. 11 shows an image of the application (Pictures shown are improved design after the field test, but the functions are essentially the same).

Fig. 11 SAVS application

Fig. 12 Record of all pick-up (red) and delivery (blue) points

Fig. 12 shows the record of all pick-up (red) and delivery (blue) points. For the last four days when all operations were automatic, there were about 680 requests and the average operation time (from request to delivery) was 22 minutes.

The field test proved that SAVS actually operates fully automatically for several days. As far as we are aware of, this is the world first operation of multi-vehicle real-time DRT system.

Fig. 13 shows the graph of total number of operations during the field test week. The system was not fully functional for the first several days, and thus could not accept all requests. The system operated without any significant errors for the last four days. The taxi company told us that their average operation of one taxy per day is 20. Therefore total of 100 operations with car is the minimum threshold we aimed at. We could actually take more than 1.5 times of the threshold. Full automatic operation of 5 cars for 4 days over average taxi's operation load in Hakodate is something we can be proud of, as the world first successful operation of real-time DRT system.

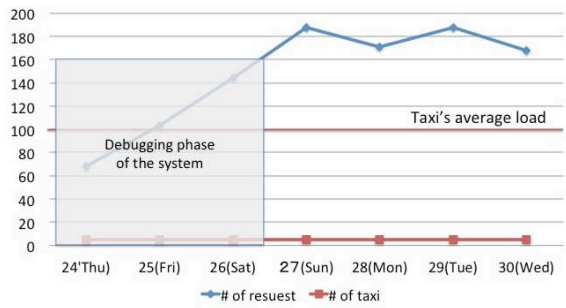

Fig. 13 Number of SAV's and their total operations for each day

Table 2 shows the statistics of the last four days' operations. Waiting time, from request to actual pick up, is rather large. It suggests that the total number of cars (5) was too small compared to the test area. However, we have to wait for the total-city simulation to decide the optimal number of vehicles per area.

Table 2 Operation statistics

date (Oct 2013)	27	28	29	30
total # of demands	191	172	178	168
average total time	22.8	23.0	20.6	18.1
waiting: request to pickup (min)	13.2	13.5	12.3	9.3
on board: pickup to delivery (min)	9.6	9.4	8.3	8.8
if on foot (min)	32.9	30.9	32.0	30.2

7 FURTHER WORK AND FUTURE PLANS

7.1 Virtual Transportation System

SAVS unifies bus and taxi systems. Since SAVS is center-controlled by a computer system, any vehicle in the system can be operated either as a bus or as a taxi. In this sense, SAVS creates a virtual layer for the public transportation system. In the future, trains, ferry boats, and even airplanes may be assimilated, so that transfer from airplane to local buses become seamless not only connection time wise but also payment wise.

This virtualization generates large operational flexibility. Here is a possibility to jump over the U-shape described in section 4.1 (Fig. 14).

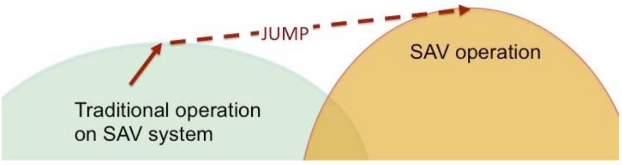

Fig. 14 Jumping over the U-shape valley

Even after all preparation for SAVS is complete, with all on-board devices and central computer system, the traditional operation of buses and taxis can be continued, since SAVS subsumes those operations. And then on particular occasions, such as Hakodate's "no my-car day", the whole vehicles are switched to SAVS mode. It can be switched back to the normal (traditional) operation mode for the next day. By switching to SAVS and back several times, people gradually get accustomed to the new operation. We can also gather data and compare their efficiencies of two modes. Only after all stake holders are convinced with the superiority of SAVS, the whole transportation system can be changed, without going through the valley in between.

7.2 Disaster Response

As one of the immediate extension of the concept of virtual transportation, the flexibility suits for emergency transportation in cases of disasters such as large fire and earthquakes.

Road configuration may change due to several roadblocks, or some path may become unusable due to extreme traffic congestion. SAV's can not only compensate for those changes but also function as probes for those blocks.

In case of communication shutdown due to power shortage or physical damage of transmission infrastructure, some alternative means must be prepared. Short-range inter-vehicle communication system or DSRC (Dedicated Short Range Communication) is one of the alternatives.

7.3 Service Unification

Unification of services may not be restricted within transportation services. Other services such as restaurant, shopping, library, and health-care can be unified [8]. For example, when you buy some goods using the Internet, you may pick it up on board a SAV.

7.4 User Interface Issues

User Interface of smart-phone application to call SAV must be upgraded. For example, the current UI allows the user either accepts or declines the proposed service. Much more sophisticated negotiation mechanism, such as requesting quicker service with higher fare, should be implemented.

8 CONCLUSION

The field test proved that SAVS actually operates fully automatically for several days. As far as we are aware of, this is the world first operation of multi-vehicle real-time DRT system.

The most significant result gained by the first cycle of SAVS development is that the system actually runs with only small number of devices. In other words, infrastructure such as GPS and mobile phone communication are sufficient for SAVS operation. User applications on smart-phones and on-board tablet terminals together with a server (Fig. 8) are only necessary additions. In other words, SAVS can be introduced into a city with relatively low cost.

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