Analysis of Public Vehicle Use with Long-term GPS Data and The Possibility of Use Optimization

—Through Working Car Project—

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Abstract— **Public vehicles are considered a valuable resource, as increasing attention has been paid to the effective use of government owned resources. In addition, the development of on-board road surface condition detector and car sharing are also considered valuable activities. Though the utility potential of public vehicles is likely high, no full-scale data analysis at municipality level exists. In this study, we analyzed the extensive data collected by the "working car project" that was established in 2014 by the National Institute of Information and Communications Technology (NICT). The goal of this study is to thoroughly explore the optimum utilization of public vehicles, and discuss the potential vehicle usage patterns. Specifically, based on vehicle operation record of Kakogawa City and Fujisawa City, we analyzed the link coverage rate, assuming that the role of daily inspecting the public roads would be given to the public vehicles, and examined the vehicle use optimization and centralized dispatching system in Kakogawa City Office. The study findings indicate the potential for car sharing.**

Keywords-Data analysis; link coverage; probe car; optimization; shared car.

I. INTRODUCTION

In recent years, the movement toward the effective use of government-owned resources has increased. For example, Request for Public Facility Management Plan [1] discussed the promotion of comprehensive and planned management of government-owned resources, such as public facilities. This trend is seen in vehicle ownership as well, while the Ministry of Internal Affairs and Communications Government Efficiency Plan developed concrete measures that aim to reduce the human and physical cost on using public vehicles within the Ministry. In addition, car sharing of vehicles is also discussed in the current literature. Taguchi et al. discussed the potential of introducing car sharing in regional cities [2], Yasumochi et al. examined the implementation of car sharing in public rental housing [3], and Hara et al. discussed quasi-auction type reservation system for car sharing [4]. Accordingly, the movement toward the effective use of public vehicles is increasing.

Meanwhile, the technological advancement in vehicle use is improving. Smart IoT (Internet of Things) promotion strategy [5] published by the Ministry of Internal Affairs and Communications considered developing autonomous car to mitigate traffic congestion. In the USA, the emergence of car sharing services, such as Uber, has been widely welcomed by users [6], which is an evidence of the potential progress toward vehicle use technology development. Within this context, the National Institute of Information and Communications Technology (NICT) established "working car project" in June 2014. The project aimed at the thorough utilization of public vehicles. GPS and sensors were installed in vehicles, allowing for extensive data analysis of public vehicles.

However, no data conversion and analysis has been previously conducted for all public vehicles that belong to each city. Thus, the effective use of public vehicles belonging to municipalities is still unknown.

Therefore, in this study, we used the vast vehicle usage data collected by the working car project for Kakogawa City, Hyogo Prefecture and Fujisawa City, Kanagawa Prefecture to perform multifaceted analysis of public vehicle usage. Specifically, we calculated the operation rate and link coverage rate of public vehicles. This would be very beneficial for measuring pavement conditions during the routine operation of public vehicles. The inspection can be carried out when the public vehicles are equipped with the on-board road surface condition detector developed by Yamada et al. [7], the road surface inspection method developed by Toyama et al. [8] that considers pavement conditions of local municipalities, or the detection method of pavement wear and tear signs of Kawasaki et al. [9] that uses a general-purpose camera in public vehicles, etc.

We also analyzed the vehicle usage data from Kakogawa City to determine the least number of vehicles required for the optimum operation without interfering with work. Based on the results, we discussed the possibility of the centralized vehicle reservation system at the city office. In this manner,

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by optimizing the vehicle operation, the practical utilization of surplus vehicles such as car sharing could be discussed.

II. SUMMARY OF COLLECTED DATA

The data used in this study is summarized in Table 1. We analyzed the data that was uploaded in real time by installing smartphones in public vehicles owned by municipalities through the “working car project” established by NICT (National Institute of Information and Communications Technology) in June 2014. Because smartphones are installed in vehicles, when the engine is running, the location information is obtained at 1-s interval. In addition, we used the vehicle ledger from each municipality to obtain information about the vehicle type, usage, number of passengers, load capacity, and storage location. Details on vehicle types are provided later. In summary, there were 14 types of vehicles in Kakogawa City (4.1(4)) and five in Fujisawa City (see Table 2).

TABLE I. SUMMARY OF THE COLLECTED DATA

Target period	1/1/2016 to 12/31/2016 12/31 inclusive
Target time period	9:00–17:00
Target vehicle number	Kakogawa City (171)/Fujisawa City (99)
Data items	Longitude and latitude of vehicles at each time Vehicle ID/Vehicle type Storage location (33 locations)
Notes	Data between 12/3–12/11 is missing

III. MEASUREMENT OF INDEX WITH LONG-TERM DATA

A. Visualization of usage

For visualization of usage, Figure 1 shows the superimposed image of route information of patrol cars over the target period of one year. Though the distance traveled in one day is not high, once multiple periods are superimposed, the overall covered area becomes visible. Figure 1 shows that the patrol cars cover a wide area. Figure 2 shows the route information of each type of vehicles obtained from the records over the target period. A school bus that belongs to Shikata Kindergarten, located in the northwest corner of the city, mostly commutes in Shikata Town. This is because Kakogawa City divides the school districts by area. Garbage trucks mostly travel the main roads that connect the new clean center (garbage processing facility for the City) and recycling center. Kakogawa City government collects garbage across the whole city; however, the present data shows that garbage trucks do not travel the whole City. This is simply due to a fact that there were garbage trucks without sensors when the present data was recorded. Doctor-patient transportation vehicles also mostly travel around Kakogawa Chuo Hospital, and there is no record of travelling across the City. In addition to the reason mentioned above for garbage trucks, Kakogawa Chuo Hospital and nearby hospitals are designated for emergency patients.

Figure 1. Kakogawa City patrol car route information. Pink shows roads that patrol cars have travelled, while ocher shows roads not travelled by patrol cars.

Figure 2. Kakogawa City vehicle travel information. Red: cleaning vehicles, blue: doctor-patient transportation vehicles, green: garbage trucks, yellow: school buses

Circles in Figure 2 show associated facilities. Specifically, orange: Shikata Kindergarten, blue: Kakogawa Chuo Hospital, green: the new cleaning center (combustible garbage disposal facility), and pink: the recycling center (incombustible materials and large garbage disposal facility).

B. Operation rate

In order to evaluate the role of transportation function each vehicle plays, we calculated the operation rate. Specifically, we analyzed the travel information of each vehicle at 10-min interval. When a vehicle was moving continuously at 5 km/h or more, we considered it as in "operation" and calculated the number of times the vehicles "operated."

The operation rate was obtained by dividing operation times by number of business days during the target period (245 weekdays). Table 2 shows the analytical results of operation rate per usage. Though there are some differences in vehicle type classification, the mean operation rate is higher for Fujisawa City than in Kakogawa City. The analysis by vehicle type indicates that medical, patrol, and public relations vehicles are most used in Kakogawa City. The operation rate of garbage trucks is notably low in Fujisawa City. However, this is most likely because the garbage collection days and time are predetermined.

C. *Link coverage rate*

In order to evaluate the role of transportation function each vehicle plays, we calculated the operation rate. Specifically, we analyzed the travel information of each vehicle at 10-min interval. When a vehicle was moving continuously at 5 km/h or more, we considered it as in "operation" and calculated the number of times the vehicles "operated." Link coverage rate shows the value of probe car in detecting the detailed road conditions in municipalities. When we applied digital road map (DRM) data of Japan Digital Road Map Association to Kakogawa City and Fujisawa City, the obtained link rates between 25,000 and 30,000, were mostly similar. We show non-time zone link coverage rate for specific time period from the beginning of measurement (January 1, 2016). If a vehicle passes even once from the beginning of measurement, we consider that the link has been covered. Results are shown in Figure 3. Both cities showed 95% or higher link coverage rate within the one year of measurement. Operation of public vehicles can cover most of the links within one year. Therefore, it is possible to install the on-board road surface condition detector described earlier on public vehicles, thus these vehicles can routinely inspect facilities and public roads. Especially, because Figure 1 shows that the patrol cars cover a wide area, it would be appropriate to install sensors in patrol cars.

Next, we divided the business hours from 9:00 to 17:00 into eight time zones (by each hour), and considered the link for each hour as a separate unit to obtain link coverage rate. Because the traffic conditions differ depending on the time zone, obtaining the link coverage rate per time zone is valuable for traffic simulation. The results of this study are shown in Figure 4. Compared to the non-time zone link coverage shown in Figure 4, the time-zone links cannot be covered in short terms, such as a month or so. It takes a year to cover the equivalent of one month for non-time zone link coverage.

In addition, the obtained non-time zone link coverage rate for Kakogawa City and Fujisawa City is increasing in mostly the same rate.

TABLE II. OPERATION RATE ANALYSIS PER USAGE (TOP: KAKOGAWA CITY AND BOTTOM: FUJISAWA CITY)

Kakogawa City	**Number of cars**	**Operation rate**	**Kakogawa City**	**Number of cars**	**Operation rate**
School bus (Yamate Kindergarten)	2	0.0	Garbage transport	1	0.4
School bus (Shikata Kindergarten)	2	44.7	Cleaning vehicles	1	3.7
Doctor-patient transportation	1	95.1	Specialized vehicles	1	33.9
Vans	1	0.0	Collection vehicles	3	0.0
Patrol cars	2	22.7	Survey vehicles	3	0.4
Kakogawa public hall	1	5.3	Higashikakogawa Public Hall	1	20.4
Kakogawanishi public hall	1	9.0	Road patrol vehicles	1	97.1
Cargo	18	42.2	Nikkosan Cemetery	1	0.0
Shared vehicles	19	52.0	Health service vehicles	1	37.1
Small cargo	17	35.1	Crime prevention and traffic patrol vehicles	1	77.1
For on-site supervisors	1	0.4	Mankien day service transport	2	21.2
For field managers	1	0.0	Ryoso Public Hall	1	0.0
Public emergency vehicles	1	35.5	Courtesy vehicles	15	41.2
Rescue operation vehicles	1	34.7	Public vehicles (multi-purpose)	17	17.6
Public relations vehicles	1	78.0	Public vehicles (disaster prevention center)	1	31.0
Material transportation vehicles	1	14.3	Public vehicles (stadiums)	1	3.3
Vehicles for office business	6	3.5	Public vehicles (Greenery Association)	1	0.0
Mini cargo	1	22.0	Public vehicles for other uses	1	0.0
Passenger vehicles	10	25.1	Unknown	27	33.6
Garbage trucks	3	31.2	Total	91	24.5
Garbage collection vehicles	1	9.8			
Fujisawa City	**Number of cars**		**Operation rate**		
Garbage collection vehicles	75		5.2		
Patrol vehicles	13		34.8		
Cargo	11		43.7		
Passenger vehicles	28		34.6		
Road patrol vehicles	1		28.6		
Total	128		29.4		

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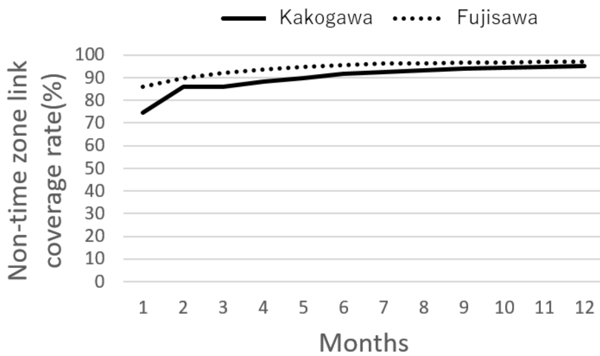

Figure 3. Non-time zone link coverage rate (Number of links: 28,917 for Kakogawa City, and 25,072 for Fujisawa City)

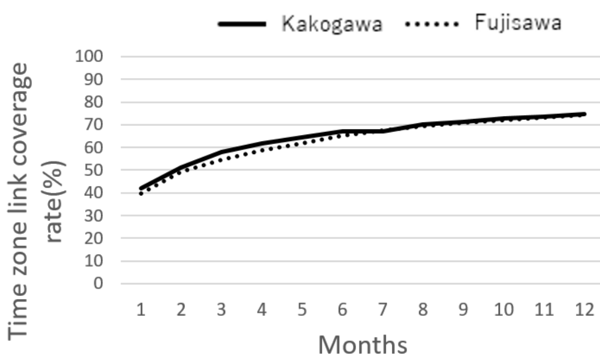

Figure 4. Time zone link coverage rate

IV. POTENTIAL DATA OPTIMIZATION

A. Vehicle operation analysis and application of optimization method for Kakogawa City

In this section, we analyze the actual travel use information of public vehicles. Without adding assumptions to usage history, we determined the least number of vehicles needed to perform the work. Furthermore, we discussed introducing a vehicle reservation system that incorporates vehicle inclusion relationship and possible usage time. We examined the potential applications of the system by applying the previously collected data to this system.

1) Data analysis

The vehicles usage data record comprises the longitude and latitude coordinates and are measured continuously. In other words, continuous tracking data precisely measured at 1-s interval is discretely stored. The storage locations and types of each vehicle are also recorded. On the basis of the obtained information, we determined whether each vehicle was at its storage location or not based on its longitude and latitude coordinate.

2) Operation optimization

We analyzed the minimum number of vehicles needed to perform the vehicle operations for each type of vehicles. Specifically, we allocated the usage history to the existing vehicles. The maximum potential usage is allocated to vehicles based on usage history (= usage is established). A new vehicle was assigned only when overlap cannot be avoided with existing vehicles. This was applied to all usage history data, in order to obtain the minimum possible number of vehicles required in operation during the target period. A schematic diagram that illustrates the operations optimization is shown in Figure 5.

Figure 5 (a) shows the usage history for vehicles A to G, with the vehicles use is divided into 5-min intervals from the beginning of the measurement for simplicity. Usage pattern during the target time is shown in shaded squares. The shading patterns show the different vehicle models, as three types of vehicles are analyzed. For operation optimization, the number of vehicles in operation is minimized by sliding the usage history, as shown in the Figure 5 (b). Vehicles C and G have overlapping use between 9:25 and 9:30, thus, this vehicle model requires two vehicles in operation.

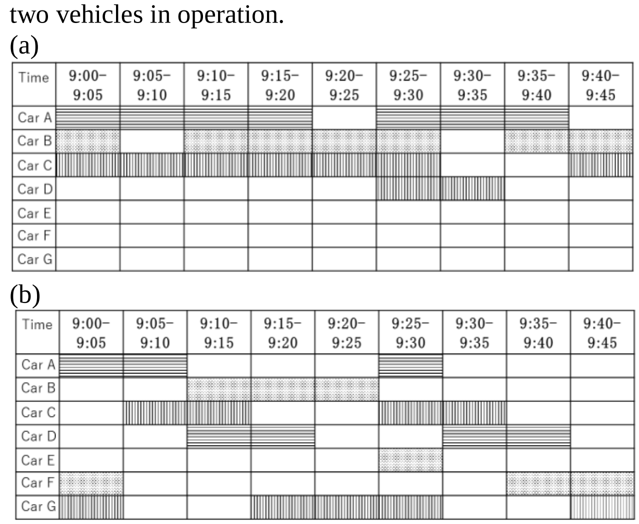

Figure 5. Conceptual diagram of operation optimization ((a): before optimization, (b): after optimization)
Translation of figures: Time, Vehicles A–G

3) Preparation of dispatch system

First, we developed a “vehicle inclusive relationship.” This is not just a dispatch table for each vehicle type, but it also includes the load capacity and the maximum passenger numbers reported in the vehicle ledger. In addition, a cross-sectional dispatch table between specific vehicles is created. Specifically, we grouped seven vehicle

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types (underlined) that can be substituted based on the reported usage of 14 vehicle types in Kakogawa City (mini cargo, standard cargo, small cargo, passenger vehicles, mini passenger vehicles, mini vehicles, light passenger vehicles, specialized vehicles, buses, garbage trucks (standard), garbage trucks, standard specialized vehicles, mini special purpose vehicles, and standard special purpose vehicles). In order to satisfy the usage demand for vehicles within this group, we added a condition in which vehicles that have more load and passenger capacity can be dispatched regardless of the vehicle type.

Next, we introduced the concept of "possible usage time." It implies the total usage demand for n-hour per a certain time zone. For example, a request is filed as "I'd like to use (XX vehicle) during 1 h between 14:00 to 17:00 on April 1." Usage requests collected in this manner can be shifted within the requested range so that the number of vehicles in operation is minimized. Figure 6 shows a schematic diagram of the developed dispatch system.

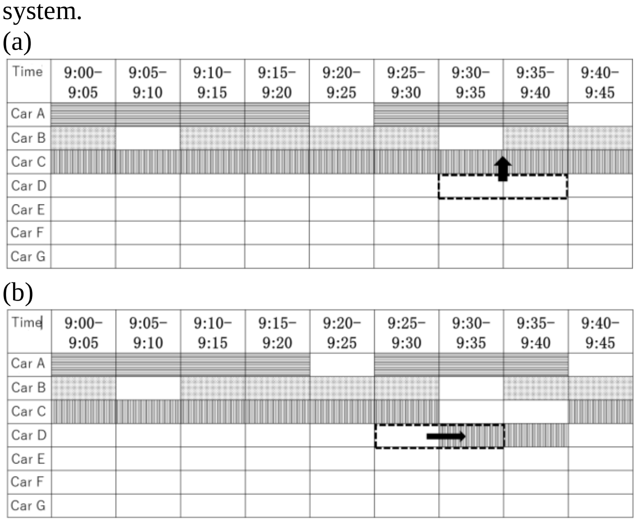

Figure 6. Schematic diagram of dispatch system ((a): shifting the reservation using the requested time, (b): vehicle dispatch table)
Translation of figures: Time, Vehicles A–G

Figure 6 shows the operation optimization system assuming that the initial usage history shown in Figure 5 (a) can be shifted within 5 min of usage history. Figure 5 (b) reveals that despite that vehicles C and G are overlapping, however, the overlap can be shifted (Figure 6 (a)).

The use between 9:25 and 9:35 has been shifted to 9:30-9:40. As a result, only three vehicles are needed to operate during this time period (Figure 6 (b)).

In this section, after the initial solution was obtained by the first fit method, the tabu search technique was used to find solution heuristically by shifting tentative reservations. In other words, we extract usage history in a random order, and assign appropriate vehicles. However, if the existing vehicles cannot respond, new vehicles are assigned. In this manner, we use the tabu value of seven and maximum combinations of 1,000/step for the initially obtained solution. The calculation is completed when there is no new solution in 1,000 steps. This is how the tabu search method can be used to obtain the optimum solution.

We applied the 2016 usage history to this reservation system based on the assumption that for processing all usage history, the usage request time is defined as plus/minus 1 h from the requested time.

B. Results

The results of data analysis in Section 4.1 (1) revealed that there were 117 vehicles that were used at least 5 min during the period. The highest frequency of usage was detected on December 28 (Wednesday) with 192 times. On this day, the mayor toured each facility, and paid the year-end greetings. As shown in Figure 7, if the pattern of usage is analyzed per time interval, the use was most notable around 9:00–9:59 at the beginning of business hours, and around 13:00–13:59 when work restarted after lunch break.

The analytical results of operation optimization in Section 4.1 (2) indicate that 96 vehicles could be operated to cover 2016 demand.

The dispatch system analysis in Section 4.1(3) shows that by introducing the vehicle inclusive relationship system, the operation could be performed with 87 vehicles. When the vehicle inclusive relationship and possible usage time under the above conditions are applied to the analysis, the operations could be performed with 77 vehicles.

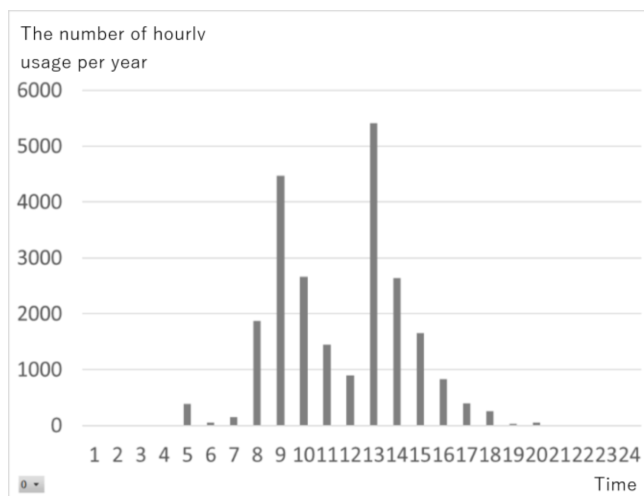

Figure 7. Frequency of usage per time zone in Kakogawa City
Translation: 2016 Kakogawa City Office time-zone vehicle usage (times)(hour)

C. Discussions

1) Data analysis and operation optimization

The data analysis indicated that 44 vehicles were not used in 2016. When the operation optimization is applied, the operations, could be performed with 96 vehicles rather that 117 vehicles; thus, the number of vehicles in operation can be reduced by 31. Assuming that the annual maintenance cost per vehicle (including insurance and automobile inspection) is 60,000 yen, if the extra 75 vehicles are removed from service, the maintenance cost can be reduced by 4,500,000 yen. If those vehicles are used for car sharing, assuming they typically charge 4,000 yen/6 h, and if n% of reduced vehicles were used on each of 245 business days, the sales would be 4000 x 245 x 75 x n/100 yen. For example, when n = 20, the sales would be 14,700,000 yen.

2) Dispatch system

When the vehicle inclusive relationship and possible usage time dispatch system with uniform 1 h lee way were applied, additional 19 vehicles could be reduced by this operation optimization. It proved the benefits of applying this dispatch system.

3) Further reduction of the number of vehicles in operation

Based on the above analysis, for example, if the appropriate measures were taken to reduce the vehicle usage on December 28 (Wednesday), the number of vehicles in operation might further be reduced. This could be achieved by reviewing the routes and time frame around facilities when the maximum usage was reported. Similarly, since there is increased vehicle use around 9:00 and 13:00, measures can be taken by shifting heavy vehicle usage periods (time when vehicle use is allowed) for each department, thus, the number of vehicles in operation can be further reduced.

Although the data between December 3 (Sunday) and December 11 (Monday) is missing, and the vehicles usage information is not recorded, the study findings regarding the optimization of vehicle operations, clearly showed the potential of practically reducing the public vehicles operations.

V. CONCLUSIONS

The above data analysis examined the actual usage of vehicles owned by Kakogawa City and Fujisawa City. The analysis showed that installing the previously described on-board road surface condition detectors, can allow for the routine inspection of public facilities and roads to be carried out by the public vehicles.

We were also able to show the potential of vehicle operations optimization. In the actual optimization, differences in vehicle usage patterns in each municipality were reported, and the method used in this study may be changed slightly in future applications. However, the study also presented a basic solution for reducing public vehicles operations.

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