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ANALYSIS ON THE IMPACTS OF DROP-OFF AND PICK-UP TRIPS ON THE ROAD TRAFFIC AROUND TRIP DESTINATIONS

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ABSTRACT

We macroscopically analysed characteristics of drop-off and pick-up travels by private vehicles including the viewpoint of weather conditions. Furthermore, we observed those vehicles' behavior on the 2-lane-2-way street bordering the school selected through the analysis, and quantitatively evaluated the impacts of that on the road traffic. As the result of the case study on the school through observation and traffic simulation, it was shown that the on-street standing of drop-off and pick-up vehicles have significant negative impacts on the performance of through traffic on the street. Additionally, we found that simultaneous increase of drop-off travel demand and through traffic volume due to the rainy weather can enlarge the duration and magnitude of the influence. The result of the study can provides a primary understanding of drop-off and pick-up behavior of private vehicles and its quantitative influence on road traffic, which can assist transportation policy consideration.

Keywords: drop-off / pick-up, on-street parking, traffic simulation, impact analysis

1. INTRODUCTION

Rushing of private vehicles to stations and schools for drop-off or pick-up in morning and evening peak might be a cause of road congestion in many cities. Generally, drop-off or pick-up spaces for private vehicles are not prepared in educational facilities such as kindergartens and schools in Japan. So that private vehicles intending to dropping off or picking up children often stand on the street near the destination for their alighting or boarding.

On the other hand, 56.6% of roads in Japan have less than 5.5m width[1)] - namely, those have equal to or less than 2 lanes, and there are many arterial roads with heavy traffic among those. When childcare or educational facilities border such roads, through traffic on the roads is possibly frustrated by on-street standing of private vehicles dropping off or picking up children at those facilities, and such a case is reported actually[2)].

Besides, Japan has a high annual precipitation which is nearly twice the world's average[3)]. It is said that rainfall might decrease people who commute by walk and bike and together increase those commute by private vehicles and public transport. In that case, negative impacts caused by drop-off and pick-up vehicles on the road traffic possibly become larger. Concerning to this, a special bus service called "rainy bus" is provided in several cities in Japan[4)]. Additional buses are put into service only within rainy morning peak period to make conveniences of bus users better and to ease up road congestion.

However, there are few cases which analyse actual conditions of drop-off or pick-up travels by private vehicles such as the types of destination facilities, shares of travels, and arrival time distributions. Additionally, we can hardly find cases that empirically and quantitatively evaluate impacts of drop-off and pick-up vehicles' behavior on the road traffic, and studies that focus on the variation of drop-off and pick-up travel demand according to weather conditions.

We macroscopically analysed characteristics of drop-off and pick-up travels by private vehicles including the viewpoint of weather conditions. Furthermore, we observed drop-off and pick-up vehicles' behavior on the street bordering the target facility selected through the analysis, and quantitatively evaluated the impacts of that on the road traffic. The result of the study can provides a primary understanding of drop-off and pick-up behavior of private vehicles and its quantitative influence on road traffic, which assist transportation policy consideration.

2. LITERATURE REVIEW

The studies related to drop-off or pick-up behavior of private vehicles can be classified roughly into two groups. The one is studies which macroscopically focus on actual conditions of drop-off or pick-up travels by private vehicles in whole of country or that in a particular urban area. Taniguchi[5)] analysed the quantitative relationships between drop-off/pick-up travels and life stages of households and modal shares of travels in each urban area based on National-wide Person-trip Survey's data. In addition, Roorda[6)] developed the transportation mode choice model on an urban scale that explicitly deals with minor transport modes such as school buses or parental escorts by private vehicles.

The other is studies which microscopically examine individual drop-off or pick-up behavior of specific age-group or that in particular region. Conducting the activity-diary survey on the elderly in the rural area, Chou[7)] described factors and their interactions, which influence decision-making of drop-off and pick-up behavior, in the time assignment model. Yarlagadda[8)] developed the simultaneous estimation model for travel mode choice and with or without of parental escort in a child's travel to school through the travel survey on San Francisco Bay Area.

Besides, there are several studies that focus on relationship between weather conditions and transportation. Noguchi[9)] examined users' levels of satisfaction for each access mode to the target station and the choice ratio of the modes by weather conditions. Cools[10)] analysed effects that weather conditions have on travel behavior change by trip purposes, which were based on the results from a questionnaire survey. In addition, Stern[11)] and Keay[12)] showed that rainfall or snow accumulation affects road capacity and traffic flow.

3. METHODOLOGY

3.1 Research design

The principal objective of this paper is to quantitatively show the impacts that drop-off and pick-up behavior of private vehicles has on the road traffic near the target facility. The aim of the study was achieved by: (1) specifying the types of facilities that attract a number of drop-off or pick-up travels by private vehicles using the data from a large-scale household travel survey on particular urban area; (2) analysing modal split of travels to each type of the facilities and its variation due to weather conditions, and time distribution of drop-off and pick-up vehicles arriving and standing there; (3) conducting observation of arrival and standing time of the drop-off and pick-up vehicles at the target facility that borders the arterial street with comparatively heavy traffic, and attract a certain number of drop-off or pick-up travels, and those travel demand possibly vary according to weather conditions; (4) reproducing present traffic situation employing a traffic simulator using the results of the observation as the parameters; (5) evaluating impacts of drop-off and pick-up behavior of private vehicles on other traffic through the comparison of the simulation results of different scenarios in which the level of traffic volume and the number of drop-off or pick-up vehicles were altered.

3.2 Analytical methods

3.2.1 Aggregate analysis on drop-off and pick-up travels by private vehicles

a. The target area

Northern Kyushu Metropolitan Area (NKMA) is the target area in this analysis, which includes Fukuoka and Kitakyushu city as its major crossroads with a population of approx. 1.5 and 1.0 million respectively (see Figure 1). NKMA has higher private vehicles' share of travels[13)] than Tokyo Metropolitan Area (TMA), central and the largest urban area in Japan, thereby being considered to have a certain number of drop-off and pick-up travels by private vehicles, and has a variety of regions from a viewpoint of travel behavior, because NKMA shows larger variance of the population distribution than TMA within determinate radius (see Figure 2). For these reason, we selected NKMA as the target area.

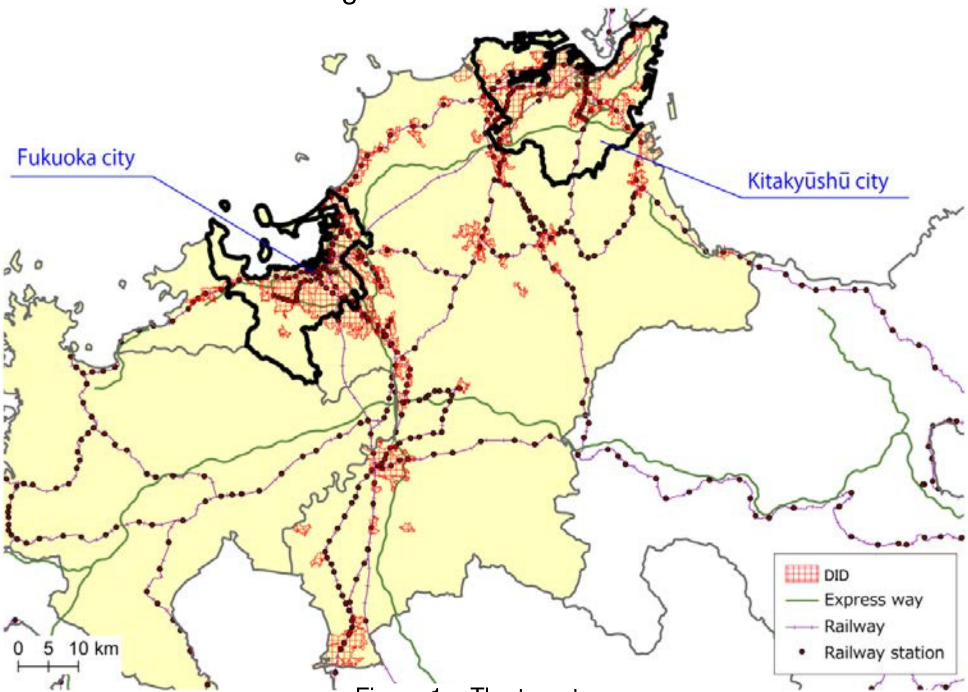

Figure 1 – The target area

b. Data

The raw data from household travel survey on NKMA held in 2005 were used for this analysis. The sample size of households and individuals were approx. 10,000 and 210,000 respectively, and the sampling ratio was approx. 5%. From this data, we extracted trip-related information such as trip purposes, transportation modes, origins and destinations, departure and arrival time, types of destination facilities, individual's identity number of car driver (if used), and number of fellow passengers from each individual's trip done in a day in autumn.

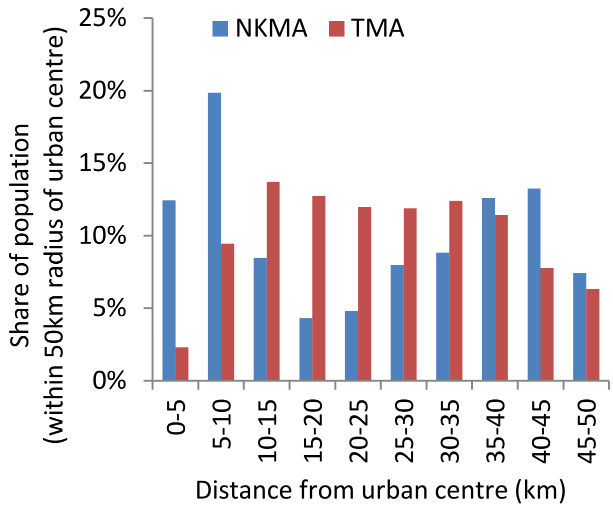

Figure 2 – Share of population within 50km radius of urban centre

c. Definition of the drop-off or pick-up travel by a private vehicle

We defined the travel that meets all conditions below as drop-off or pick-up travels by a private vehicle.

(1) The travel should be achieved by using a private vehicle totally or partially; For example, the travel transferring from a private vehicle to a railway and then going to the final destination meets this condition.
(2) The purpose of a travel should be to drop-off or pick-up when the traveler drives a car by oneself.
(3) The travel purpose of the car driver should be to drop-off or pick-up when the traveler doesn't drive a car by oneself.
(4) A home-based trip-chain of car driver is different from that of the fellow passengers; For example, the travel that a mother dropping her son off at a hospital subsequently staying there together and then homing together doesn't meet this condition, because trip-chains of the mother (driver) and her son (passenger) are identical. However, for this example, the condition would be met when a mother goes home alone after dropping off and then picking her son up at the hospital again subsequently homing together.

d. Determination of the drop-off and pick-up travel by a private vehicle

It can be directly determined from a travel data whether the travel meet the condition (1) and (2) described above. On the other hand, it is necessary to match trips and trip-chains between a car driver and the fellow passengers in order to examine the condition (3) and (4). This is done as follows. [1] Make the identify number of the car driver and the passenger respectively from the household and individual's sequential number; [2] Link all car-related trips of the driver to that of the passenger through the car driver's identify number; [3] Of these pairs of linked trips, select the one that have identical departure and arrival time; [4] Link the trip-chain including the selected trip of the driver to that of the corresponding passenger.

3.2.2 Observation of drop-off and pick-up behavior of private vehicles

a. The target facility

It was shown that educational facilities such as schools attract a large portion of drop-off and pick-up travels and those demands can vary due to weather conditions from the results of the aggregate analysis of travels (see Figure 9 and Figure 21).

For this reason, we extracted School X as the target of this observation by overlaying positional and attribute data of schools[14)] on that of roads[15)] with GIS. School X borders the 2-lane-2-way street with 5.5m width that has no centre median. Peak hour traffic volume of the road is on the top 20% group of Japanese urban 2-lane arterial roads (see Figure 3). Besides, school X consists of an elementary school, a high school, and a two-year college, thereby having approx. 2,000 students in total.

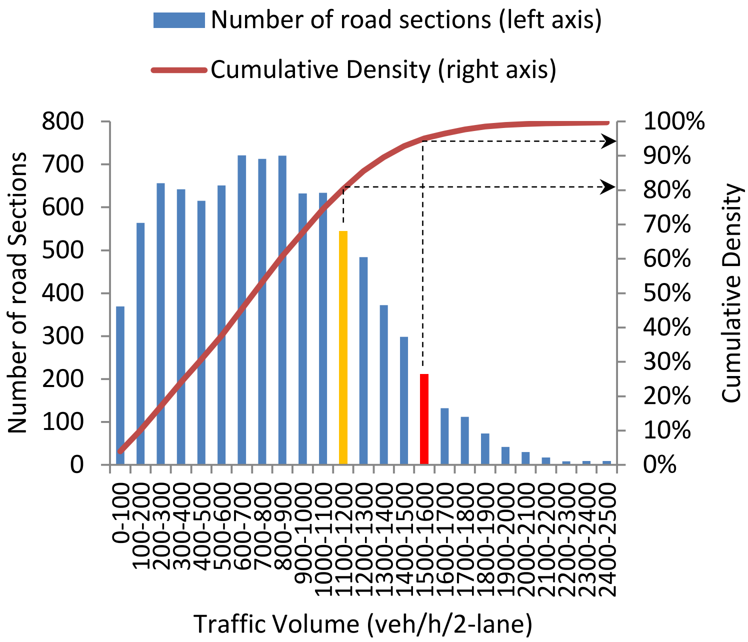

Figure 3 – Numbers of road sections by traffic volume rank

b. Survey design

School X with the circumference is shown in Figure 4. Direction 1 leads to a busy railway station (400m away) and to major national road (1.6km away). The weekdays' peak hour (8:00-9:00) traffic volume of Direction 1 is 740 including 2.6% of large vehicles, which accounts for approx. 65% of total traffic of both directions. In addition, there is no physically-divided sidewalk on this side of the street so that pedestrians are walking on 0.6m width of side strip.

On the other hand, Direction 2 leads to an interchange of a motor way (2km away) and to CBD of the city (13km away). The weekdays' peak hour traffic volume is 393 including 9.2% of large vehicles. Additionally, a 2.5m width of sidewalk is mounted on this side of the street. Both Direction 1 and 2 are used for bus routes, and one bus stop is

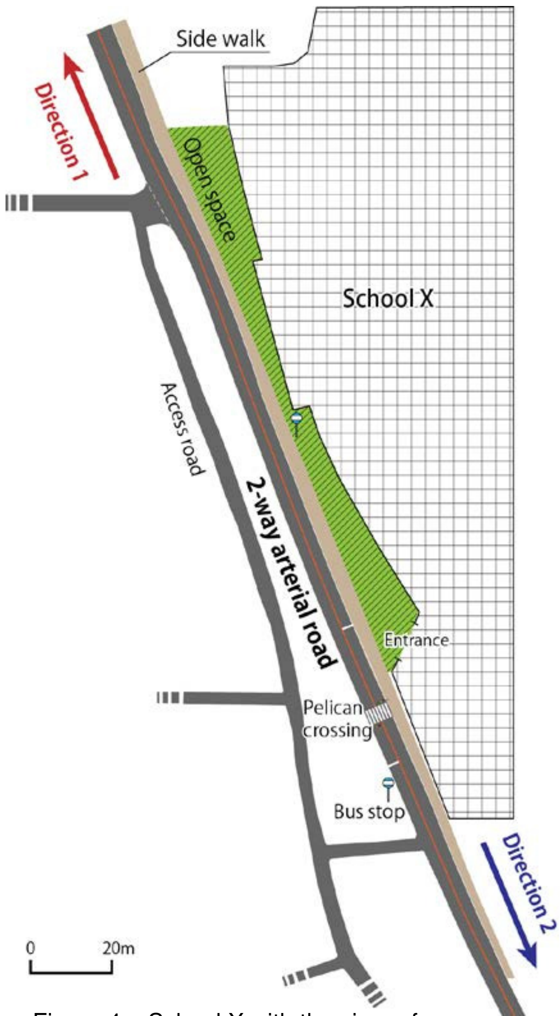

Figure 4 – School X with the circumference

located on each side of the street within the area shown in Figure 4. Headways of the buses in Direction 1 and 2 are 3.7 and 6.6 min respectively in weekdays' peak hour. Pedestrians can cross the street through only one pelican crossing within the area in Figure 4. The pedestrian green is 20 sec.

In a sunny weekday in autumn, we observed private vehicles arriving at School X for dropping off or picking up the students in the period of going-school (7:15-8:30) and going-home (14:30-17:00) respectively. Observers were assigned to four drop-off or pick-up points where we had found in the pilot survey. We monitored parking and standing locations, arrival and departure time, and a number of boarding or alighting passengers of the drop-off and pick-up vehicles. In parallel, we recorded the traffic volume of bikes, starting and ending time of pedestrian green, a number of crossing pedestrians, and dwelling time of route busses at the bus stops.

3.2.3 Analysis on the impacts of drop-off and pick-up behavior on the road traffic

We observed no drop-off or pick-up vehicles standing on the street in the going-home period (14:30-17:00), thereby conducting this analysis only for the going-school period (7:15-8:30).

a. Reproducing the present traffic situation

We reproduced the present traffic situation including the behavior of drop-off and pick-up vehicles employing the multi-modal traffic simulator- VISSIM (version 5.30- 10). The principal parameters of the simulation are shown in Table 1. The reproducibility of the present traffic situation was verified through comparing the estimated and actual measured values of traffic flow rate and average travel speed of the target street.

Table 1 – The principal parameters of the simulation

Elements		Parameters
Driving behavior	Cars	- When there is a sufficient gap in the oncoming traffic, cars overtake the standing drop-off / pick-up vehicles on the street using the oncoming lane, and return to the original lane immediately. - In the situation above, oncoming cars stop at a safe position until overtaking cars finish returning to original lane. - When there is a sufficient lateral gap, cars overtake pedestrians and bikes on the right side on the same lane.
	Bikes	- Bikes keep left. - When there is a sufficient lateral gap, bikes overtake pedestrians and cars on the right and left side on the same lane respectively.
Through traffic		- All vehicles enter the network according to a Poisson distribution. - Input traffic volume of cars is based on the result of National Road Traffic Census 2010, and of pedestrians and bikes are observed in this study (see 3.2.2).
Drop-off and pick-up vehicles		- The standing location, arrival and departure time, and a number of boarding or alighting passengers are based on the result of the observation in this study (see 3.2.2). - Standing locations and entering times into the network are fixed.

b. Analysis on the impacts of drop-off and pick-up behavior on the road traffic

(1) Simulation scenarios

We verified reproducibility of present traffic situation, and then made simulation scenarios shown in Table 2, subsequently carried out the traffic simulation for each scenario.

Table 2 – Simulation scenarios

Cases	Abbreviations	Descriptions	Levels of parameters	
			Through traffic	D/P vehicles
00	Prs.	Present situation	1.0	1.0
01	Prs.-O	Case00 without D/P vehicles	1.0	0
10	Trf.+40%	Possible level of almost heaviest through traffic: Present D/P vehicles with +40% through traffic	1.4	1.0
11	Trf.+40%-O	Case10 without D/P vehicles	1.4	0
20	2DV. - Trf.+10%	Possibly increased D/P demand and through traffic according to rainfall: Doubled D/P vehicles with +10% through traffic	1.1	2.0
21	Trf.+10%-O	Case20 without D/P vehicles	1.1	0

Note: "D/P" is the abbreviation for "drop-off and pick-up"

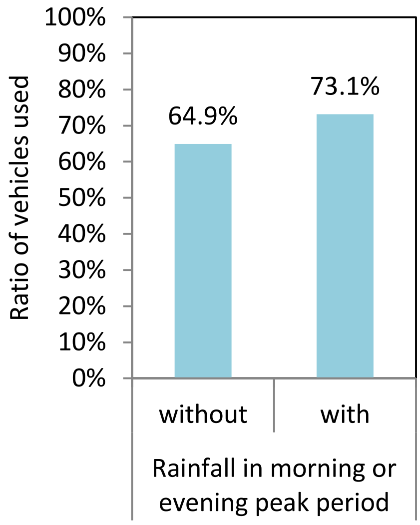

Figure 5 – The use ratio of private vehicles by weather condition

Peak hour traffic volume on the top 5% group of Japanese urban 2-lane arterial roads is 1.4 times more than that on the target street in this case study (see Figure 3). This value was considered the maximum volume of hourly traffic on the road sections similar to the street in this case study. This possible maximum traffic volume with and without drop-off and pick-up travel demand were simulated in Case 10 and 11 respectively.

In Case 20, we assumed the number of drop-off and pick-up vehicles is 2 times that of present. This is because the number of car-passenger trips to urban schools doubles in the case of rainy weather relative to clear weather (see Figure 21). Arrival times of drop-off and pick-up vehicles added in case20 were generated according to present distribution, and the standing time of each vehicle was uniformity 20 sec which is the mode value of that in present situation. Furthermore, through traffic volume is 10% larger than that of present in this scenario. This is because the use ratio of private vehicles increases by approx. 10% in the case of rainy weather relative to clear weather (see Figure 5).

The result shown in Figure 5 was obtained from aggregating vehicles' travel data from National Road Traffic Census in 2005 in which registered passenger cars' usage (approx. 750 thousand vehicles; sampling ratio of 1.3%) was investigated on a day in autumn. Matching each date on which a vehicle surveyed and the weather[16] of the same date, we aggregated the use ratio of private vehicle by weather conditions.

(2) Comparison of the simulation results

Evaluation indicators for the six simulation scenarios (see Table 2) are shown in Table 3.

Table 3 – Evaluation indicators

Indicators	Descriptions
Avg. travel speed (km/h)	Total distance traveled divided by total travel time.
Avg. delay time (sec/veh.)	Average delay from ideal travel time without any stops due to signals and traffic congestion.
Avg. queue length (m)	Average length of the queue measured at the counting point on Direction 1.
Number of lane changes	Total numbers of lane changes to the oncoming lane to overtake drop-off and pick-up vehicles standing on the street.

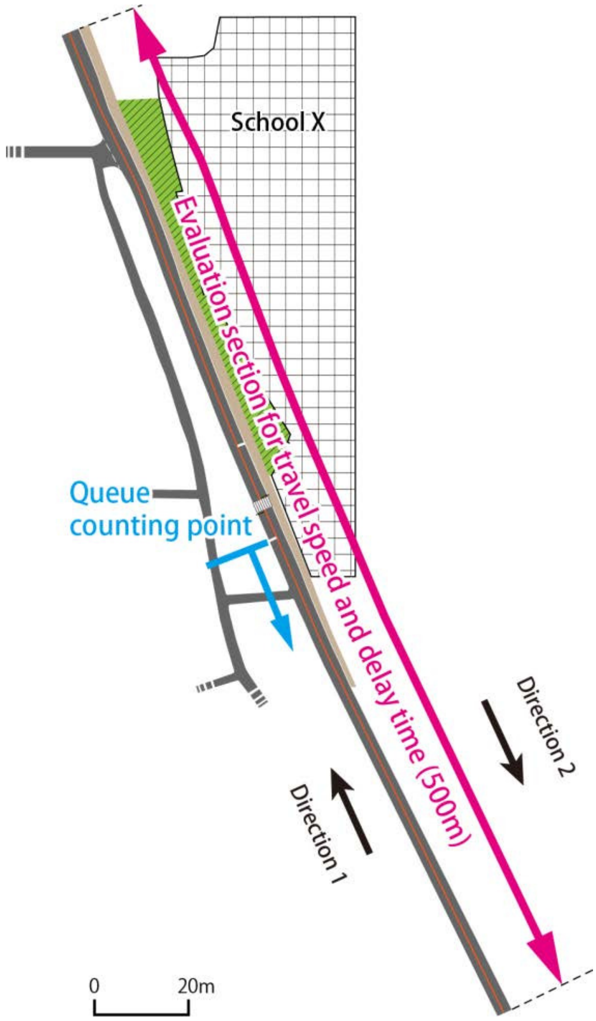

Figure 6 – The evaluation section and the queue counting point

Both average travel speed and average delay time are calculated exclude pedestrians and bikes, and are measured in 500m of common road section shown in Figure 6. Queue length of cars is measured at the counting point on the stop line of the pelican crossing on Direction 1 near the area at which the largest number of drop-off vehicles arrived in the survey (see 4.3.1). Each evaluation indicator is arithmetic mean value of the results of 10 simulation runs in which traffic generating patterns are different.

Comparing the evaluation indicators of Case 00 (present situation) and that of Case 01 (Case 00 without drop-off and pick-up travel demand), we analysed the impacts of present drop-off and pick-up travel demand on present through traffic. Similarly, comparing the indicators of Case 10 (present drop-off and pick-up travel demand with +40% through traffic) and that of Case 11 (Case 10 without drop-off and pick-up travel demand), we analysed the impacts of present drop-off and pick-up travel demand on the maximum level of through traffic. In addition, comparing the indicators of Case 20 (doubled drop-off and pick-up travel demand with +10% through traffic) and that of Case 21 (Case 20 without drop-off and pick-up travel demand), we analysed the possible impacts of increased drop-off and pick-up travel demand on raised through traffic due to rainy weather.

(3) Calculation of social costs derived from drop-off and pick-up travel demand

As examples of social cost, we calculated the annual time loss and the CO2 emission according to the delay and the travel speed reduction of through traffic. In this calculation, the number of weekdays was assumed to be 298.

Annual time loss was figured out through multiplying the difference of total time loss between Case 00 (present situation) and Case 01 (Case 00 without drop-off and pick-up travel demand) by time values (see Table 4). These time values are shown in a national guideline[17] for cost and benefit analysis of public projects. Note that we converted yen into US dollars with the exchange rate: 1 US dollar equals to 85 yen, which was the average rate over 2010-2012.

Table 4 – Time values

Vehicle type	Time value(yen/min)
Passenger cars	40.1
Large freight vehicles	64.18
Buses	374.27

CO_2 emission from road traffic was calculated through multiplying the traffic volumes by CO_2 emission factors depending on the vehicles' average travel speed "v" (see Table 5). These factors had been estimated by a national institute[18] for evaluation of road projects. We considered the difference of CO_2 emission between Case 00 (present situation) and Case 01 (Case 00 without drop-off and pick-up travel demand) the social cost.

Table 5 – CO_2 emission factor

Vehicle type	CO2 emission factor expression (g-CO2/km)
Passenger vehicle	$EF = 1864.3 / v + -2.3201\ v + 0.020070\ v^2 + 166.85$
Small freight vehicle	$EF = 528.18 / v + -4.9862\ v + 0.039262\ v^2 + 308.57$
Large freight vehicle	$EF = 50.285 / v + -27.312\ v + 0.208750\ v^2 + 1592.70$
Bus	$EF = 2784.6 / v + -12.752\ v + 0.105900\ v^2 + 854.18$

4. RESULTS

4.1 Characteristics of drop-off and pick-up travels by private vehicles

4.1.1 Drop-off and pick-up vehicles' share of trips

Among car-related trips, 10% is for drop-off or pick-up travel, 65% for driver-only travel and 25% for trips with passengers, the last of which includes some drop-off trips due the data availability limitation (see Figure 7).

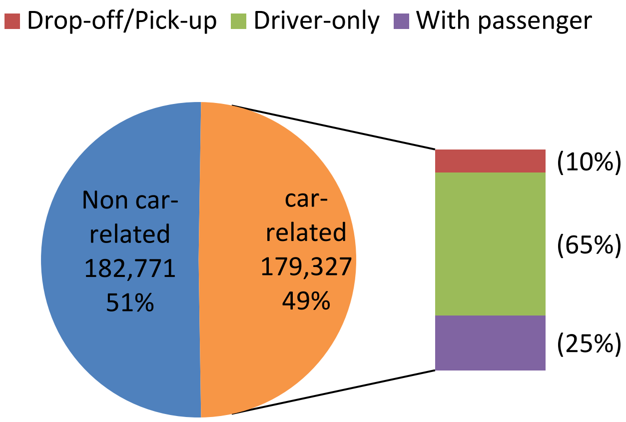

Figure 7 – Drop-off and pick-up vehicles' share of trips

4.1.2 Breakdown of drop-off and pick-up trips

a. Cross tabulation by passenger's trip purpose

Among drop-off trips for passenger's commuting to work, 70% is directly access to the final destinations, and 30% is access to stations for transferring to public transport (see Figure 8).

On the other hand, about 90% of drop-off trips for passenger's commuting to school are directly access to the final destinations, which rate is larger than that of commuting to work. Besides, almost all drop-off trips for passenger's private businesses are directly access to the final destinations.

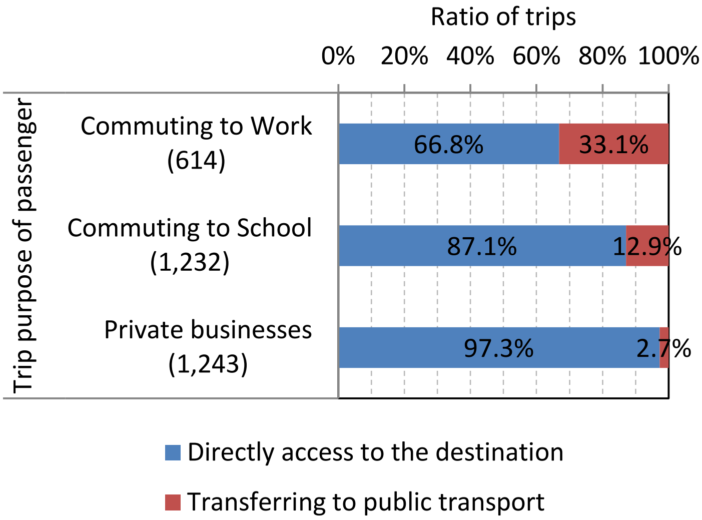

Figure 8 – Trip characteristics by passenger's trip purpose

b. Composition of drop-off and pick-up trips by the types of destination facilities

Educational facilities have the largest share of drop-off and pick-up trips' destinations followed by transportation facilities such as railway stations. These two facilities account for more than 70% of all, thereby being vast majority in NKMA (see Figure 9).

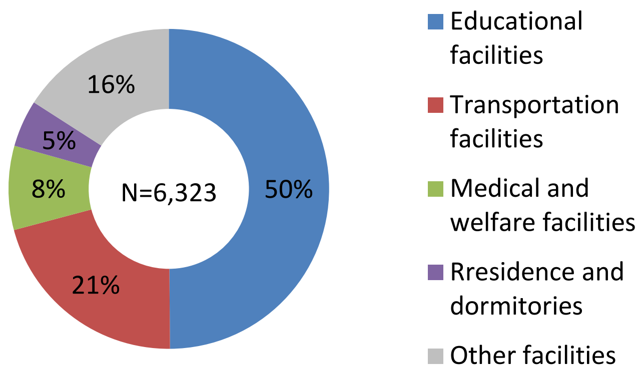

Figure 9 – Composition of drop-off and pick-up trips by the types of destination facilities

4.1.3 Time distribution of drop-off and pick-up trips

We analysed time distribution of the number of drop-off and pick-up trips arriving and staying at educational and transportation facilities which are majority of those trips' destinations.

a. Arrival time distribution of drop-off and pick-up trips

For educational and transportation facility, the shapes of the distribution are similar to each other. However, the peak hour of drop-off trips' arrival at educational facilities is 1 hour later than that of transportation facilities, and conversely, the arrival peak of pick-up trips at educational facilities is 1 hour earlier (see Figure 10 and Figure 11).

b. Time distribution of the number of drop-off and pick-up trips staying at the destination

The number of the drop-off and pick-up trips staying at destination was estimated in each time period, calculating staying time and the number of staying trips by using the difference between arrival time of dropping off and the departure time of the subsequent trip (see Figure 12 and Figure 13).

For every type of destination facility, at which the number of drop-off trips staying is relatively larger than that of pick-up trips. This implies that the staying time of pick-up trips is longer than that of drop-off trips.

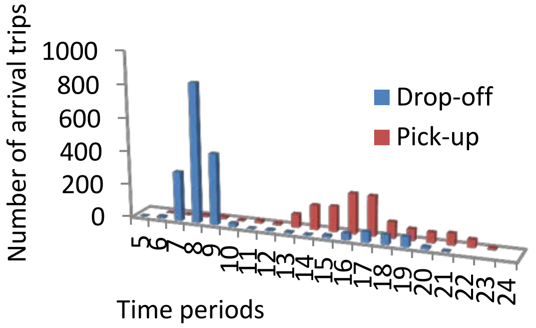

Figure 10 – Arrival time distribution of drop-off and pick-up trips at schools

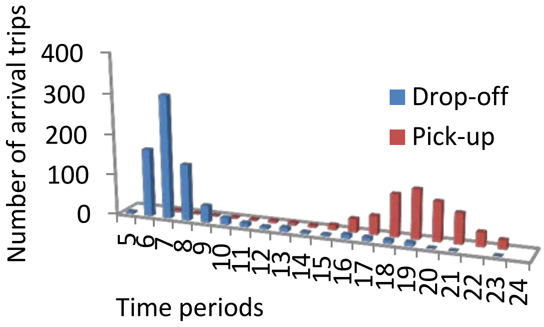

Figure 11 – Arrival time distribution of drop-off and pick-up trips at stations

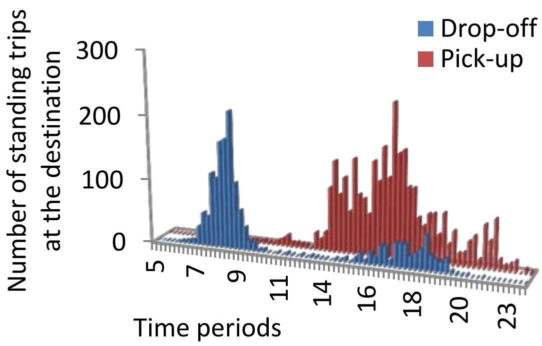

Figure 12 – Time distribution of the number of drop-off and pick-up trips staying at schools

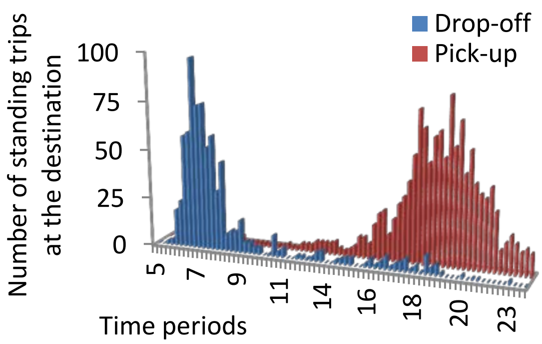

Figure 13 – Time distribution of the number of drop-off and pick-up trips staying at stations

4.2 Characteristics of trips to the major type of facility

4.2.1 Characteristics of trips to railway stations

a. Cross tabulation by location of stations

We divided the areas where railway stations locate into three location types: (1) "Urban core": Central Business District of Fukuoka and Kitakyushu city; (2) "DID": densely-inhabited district except urban

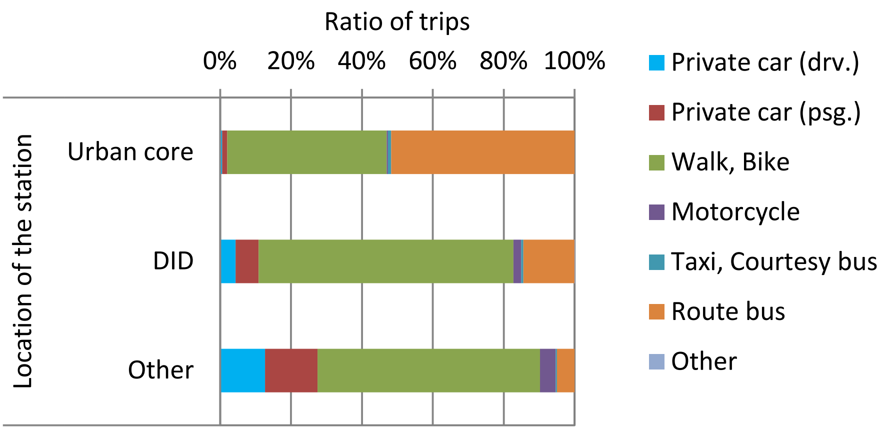

Figure 14 – Modal shares by location of stations

core; (3) "Other": other areas, and then analysed the characteristics of trips access to railway stations for transferring.

The more populated where the station is, the larger the private car's share of going-station trips (see Figure 14). The private car's share reaches 30% when the station is in "Other". Besides, "Urban core" has large route bus's share of going-station trips. This is because people appear to easily get to the railway station in "Urban core" with densely-provided bus services.

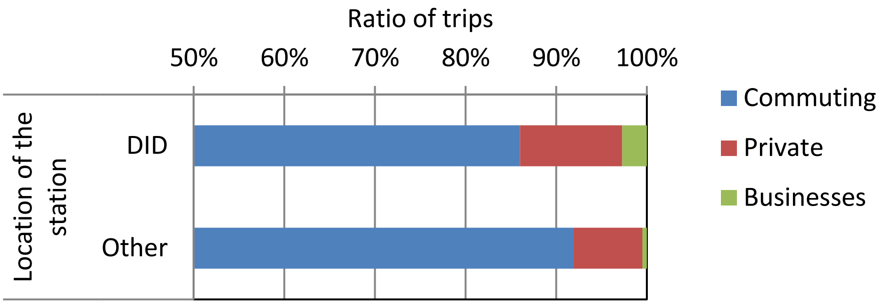

Figure 15 – Trip purposes' shares by location of stations

On the other hand, concerning to the travel purpose of station users, the ratio of private and business trips for the station in "DID" is higher than that for the station in "Other" (see Figure 15). This reason appears to be that the accessibility to the urban core is high for stations in "DID" so that the railway is useful to go there for daily private activity such as shopping.

b. Cross tabulation by function of stations

The car-passenger and the route bus's share of going-station trips are larger in interchange stations than that in other stations (see Figure 16). The per-station number of going-station trips by private vehicles is distinguished in interchange stations in "DID" and "Other", and is small in "Urban core" (see Figure 17). The reason seems to be that stations in suburban areas have a certain number of kiss-and-ride or park-and-ride travels.

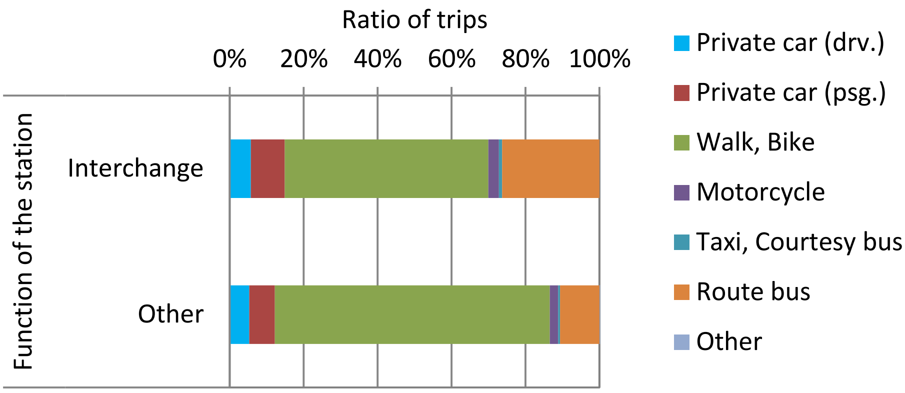

Figure 16 – Modal shares by function of stations

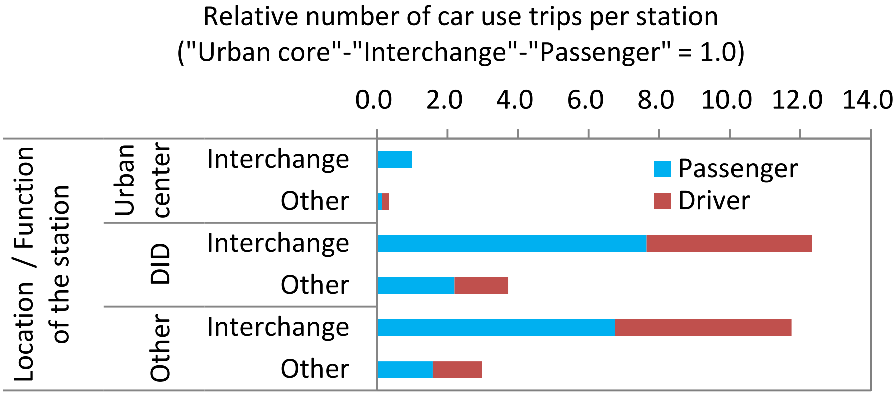

Figure 17 – Relative number of car use trips per station by attributes

c. Cross tabulation by weather conditions

Matching each date on which a person travels and the weather of the same date, we aggregated going-station trips by weather condition. The use rate of walk and bike decrease by approx. 2 %age points, and that of car-passenger and route bus rise by approx. 1 %age point respectively in the case of rainy weather (see Figure 18).

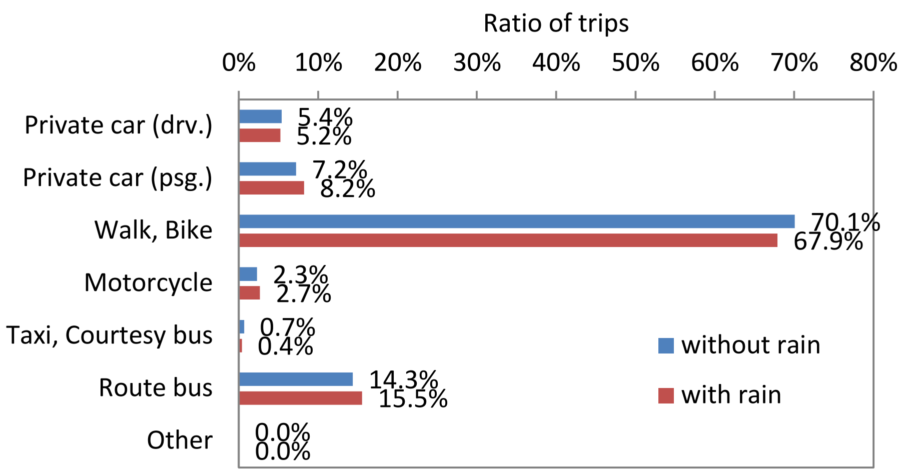

Figure 18 – Modal shares of going-station trips by weather conditions

4.2.2 Characteristics of trips to schools

a. Cross tabulation by location and school type

The private vehicle's share of trips to kindergartens and schools for the disabled is large, which tends to increase when the school is in the suburban and rural area (see Figure 19).

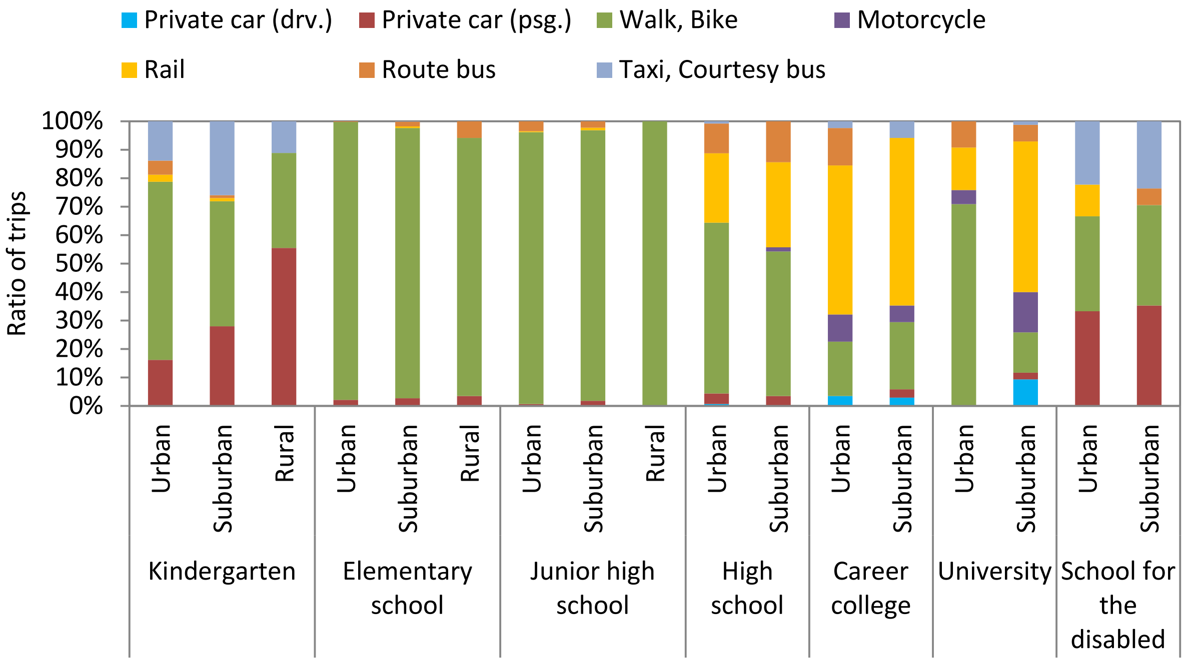

Figure 19 – Modal shares of going-school trips by location and school type

For elementary schools and junior high schools, the ratio of trips by private vehicles trips is critically high, and is almost constant regardless of locations of the schools. Concerning to high schools and universities, the railway and route bus's share is large, which especially rises when the school is in the suburban area. Additionally, the ratio of car-driving trips is somewhat high in suburban universities.

The per-school number of going-school trips by private vehicles is lager in high schools and universities with a big population of students than in kindergartens and schools for disabled which have high ratio of trips by private vehicles (see Figure 20). In addition, Elementary schools and junior high schools also have a certain amount of that.

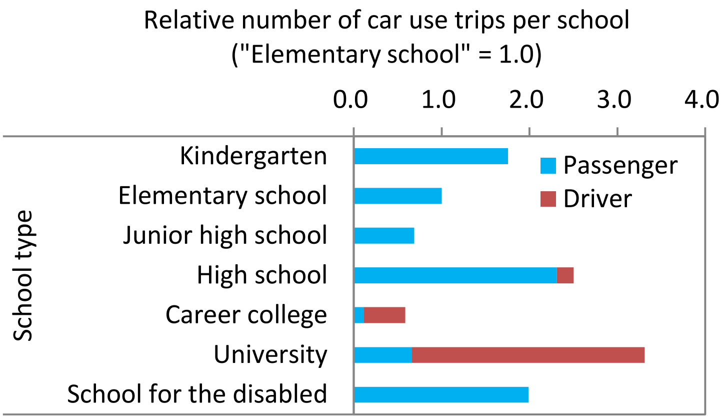

Figure 20 – Relative number of car use trips per school by school types

b. Cross tabulation by weather conditions

We aggregated trips to schools in urban areas by weather conditions. As is the case with railway stations, the use rate of walk and bike decrease by approx. 5 %age points, and that of car-passenger and railway together rise by approx. 2 %age point in case of rainy weather (see Figure 21).

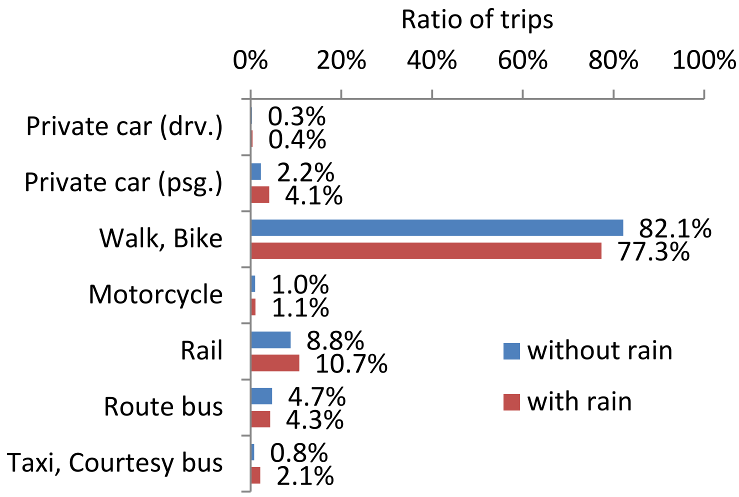

Figure 21 – Modal shares of going-school trips by weather conditions

4.3 The impacts of drop-off and pick-up vehicles' behavior on the road traffic

4.3.1 Results of the observation of drop-off and pick-up vehicles

We observed drop-off and pick-up vehicles arriving at School X. As a result, collectively 20 vehicles standing at P1-P4 (see Table 6 and Figure 22) for dropping students off were counted during 7:15-8:30. All of these vehicles were standing there not for picking students up but for dropping them off. Among drop-off vehicles, 85% used P1 or P2, the mode and maximum value of their dwelling time were 20 and 240sec respectively.

Besides, we observed only one pick-up vehicle arriving at P5 shown in Figure 22 during 14:30-17:00. This vehicle, however, has rarely influenced on through traffic because it was standing inside of coin-parking.

Table 6 – The number of drop-off vehicles observed

Time periods	Number of drop-off vehicles.				
	P1	P2	P3	P4	Total
7:15 - 7:30	2	0	0	0	2
7:30 - 7:45	2	0	1	0	3
7:45 - 8:00	2	3	0	0	5
8:00 - 8:15	1	6	0	0	7
8:15 - 8:30	0	1	1	1	3
Total	7	10	2	1	20

4.3.2 Results of the reproduction of present traffic situation.

Comparison of the results of the observation and the simulation during 7:15-8:30 is shown in Table 7. As that, the through traffic volume was reproduced accurately. For the average travel speed, the reproducibility was acquired almost appropriately when the difference of observation time period and section length are taken into account, which might affect the data in Direction 2.

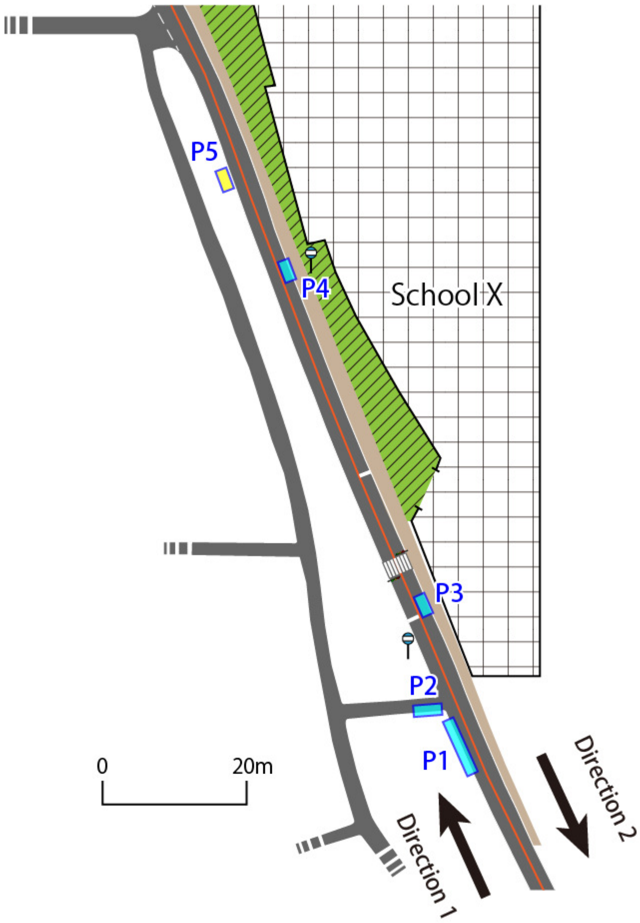

Figure 22 – On-street standing points of observed drop-off and pick-up vehicles

Table 7 – Comparison of the results of observation and simulation

Evaluation Indicators		Values during 7:15-8:30		
		(a) Observed	(b) Simulation result (Case00)	Difference ratio : (b)/(a) -1
Through traffic volume (veh./hr.)	Direction1	379*	370	-2%
	Direction2	355*	358	+1%
Average travel speed (km/h)	Direction1	22.0**	20.5	-7%
	Direction2	24.8**	32.0	+29%

Note) * Weighted mean of the results for 7:00-8:00 and 8:00-9:00
** Results for 8:00-9:00 in 1.5km section including the evaluation section of this study.

4.3.3 Results of the analysis

a. Traffic volume

Traffic volume except pedestrians, bikes, and drop-off vehicles are shown in Figure 23. Note that traffic volume was counted when vehicles have passed the start line of the evaluation section. The feature of Direction 1 is that the traffic volume rapidly rose 4 times the previous period at 8:00. The number of drop-off vehicles in case "Prs." (Case 00) and case "2DV.-Trf.+10%" (Case 20) are shown in Figure 24. The largest number of drop-off vehicles passed during 8:00-8:15 on Direction 1.

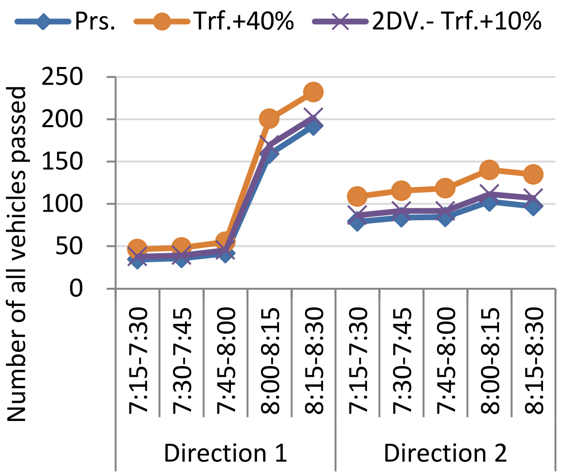

Figure 23 – Traffic volume except pedestrians, bikes, and drop-off vehicles

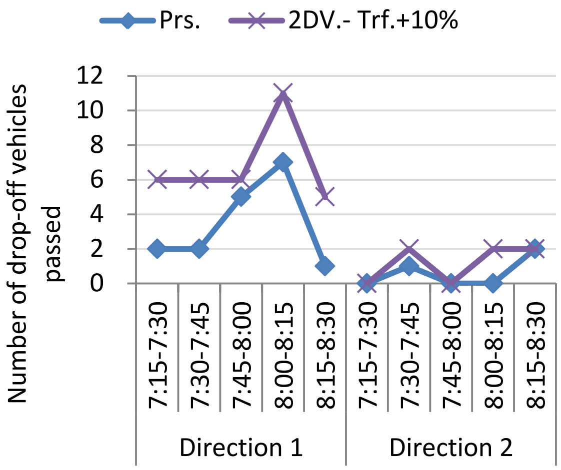

Figure 24 – Traffic volume of drop-off vehicles

b. The evaluation indicators

The average travel speed declined to 20km/h after 8:00, at which through traffic increased, for all cases (see Figure 25). The level of speed was the highest in case "Prs.-O", and that in case "Trf.+40%" and "2DV.-Trf.+10%" was the lowest until 8:00 and after 8:00 respectively. In addition, differences among the cases appeared to be clear after 8 a.m. The average delay time is a sort of inverse index of average travel speed. As well, its difference among the cases must be in inverse relation to that of average travel speed (see Figure 26).

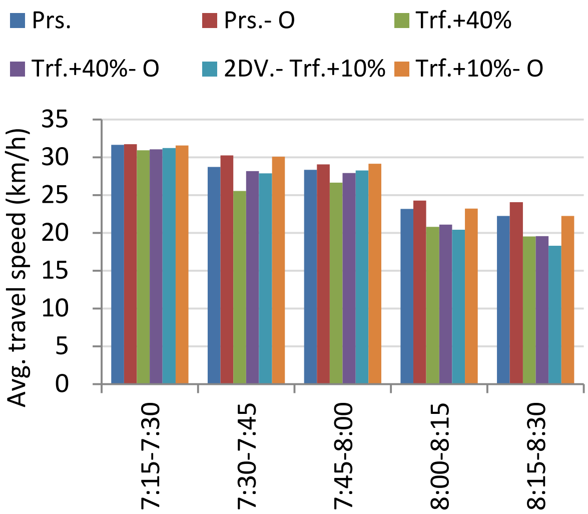

Figure 25 –Estimated average travel speed

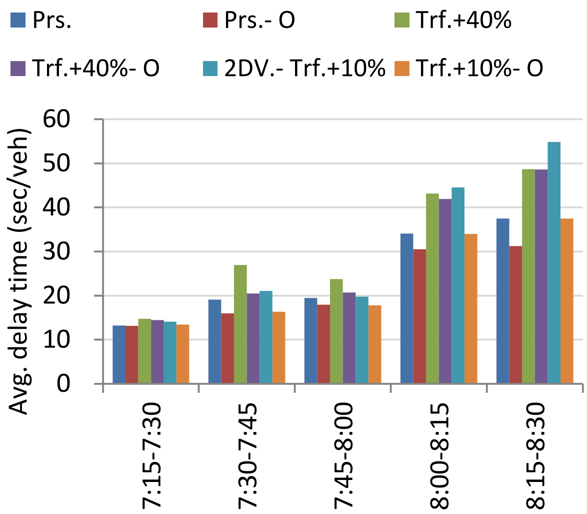

Figure 26 – Estimated average delay time

The average queue length at the counting point of Direction 1 rapidly increased after 8:00 for all cases, especially the rising in case "Trf.+40%" and "Trf.+40%-O" were featured (see Figure 27). The reaction of the average queue length to variation of through traffic volume is more sensitive than that of the average travel speed and average delay time.

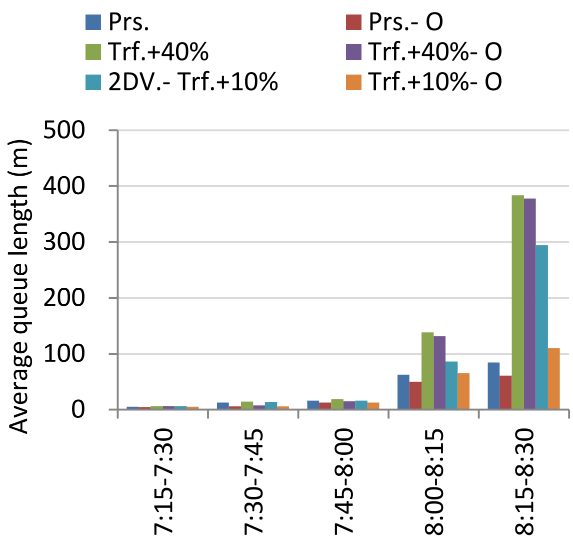

Figure 27 –Estimated average queue length

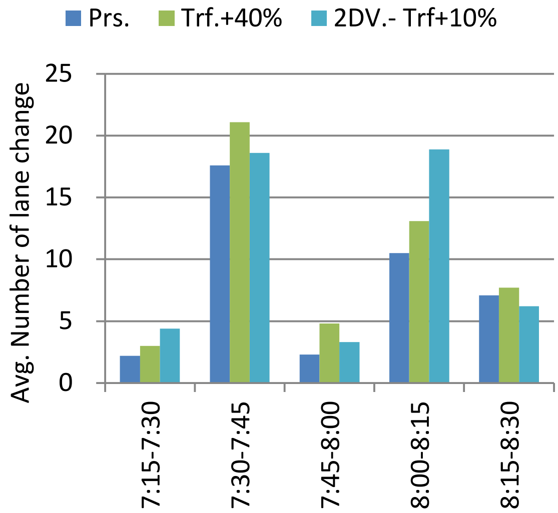

Figure 28 –Estimated average number of lane changes

The number of lane changes to overtake drop-off vehicles standing on the street increased for 7:30-7:45 and 8:00-8:15 when large number of those vehicles arrived (see Figure 28). In case "Trf.+40%", the number of lane changes is the largest as a whole time periods. Additionally, The magnitude of the value for 8:00-8:15 in case "2DV.- Trf.+10%" in which the largest number of drop-off vehicles arrived was featured.

c. The impacts of drop-off and pick-up vehicles on the road traffic

The reduction ratio of average travel speed according to drop-off vehicles' behavior is shown in Figure 29. Note that the symbols of "*", "**", and "***" attached to the bar chat show significances of the differences of the mean value for 10 simulation runs between two cases being compared with, which are 1, 5, and 10% respectively.

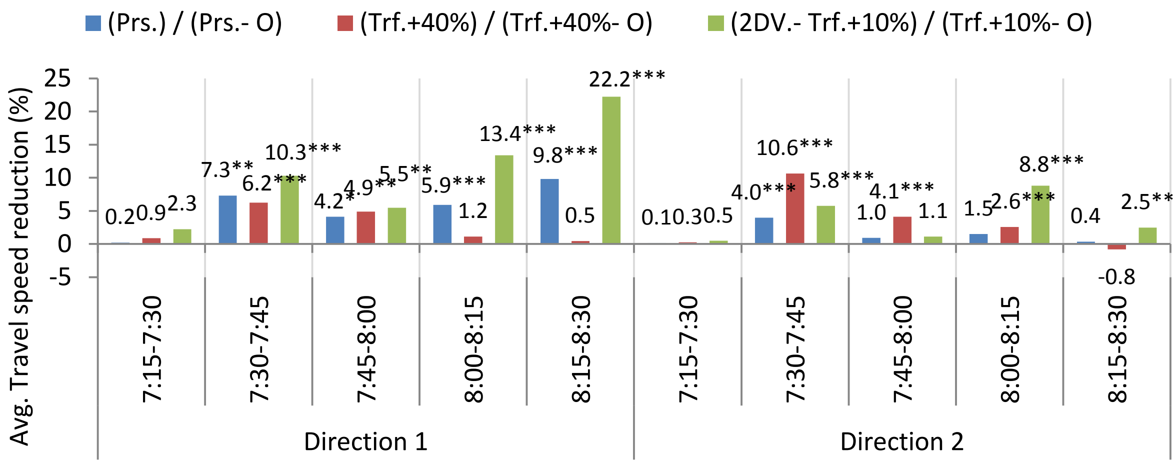

Figure 29 –The reduction ratio of average travel speed according to drop-off vehicles' behavior

For the comparison of "Prs." versus "Prs.-O", the average travel speed of through traffic significantly declined by 4-10% due to the drop-off vehicles during 7:30-8:30 on Direction 1 and 7:30-7:45 on Direction 2. Similar to this, concerning the comparison of case "Trf.+40%" versus "Trf.+40%-O", the average travel speed of through traffic significantly reduced by 3-11% during 7:30-8:00 on Direction 1 and 7:30-8:15 on Direction 2 according to the drop-off vehicles' behavior under the maximum level of through traffic. The heavier the through traffic is, the greater the impacts that drop-off vehicles have on the through traffic on Direction 2 than that on Direction 1. This is because; the increase of the number of lane changes to overtake drop-off vehicles raised the opportunities of breaking and stopping of the oncoming traffic.

For the comparison of "2DV.-Trf.+10%" versus "Trf.+10%-O", the average travel speed significantly dropped by 3-22% for all time period of every section. Not only the duration for which drop-off vehicles' behavior affects the through traffic but also the magnitude of the influence were enlarged in the case of rainy weather than that of clear weather (present situation).

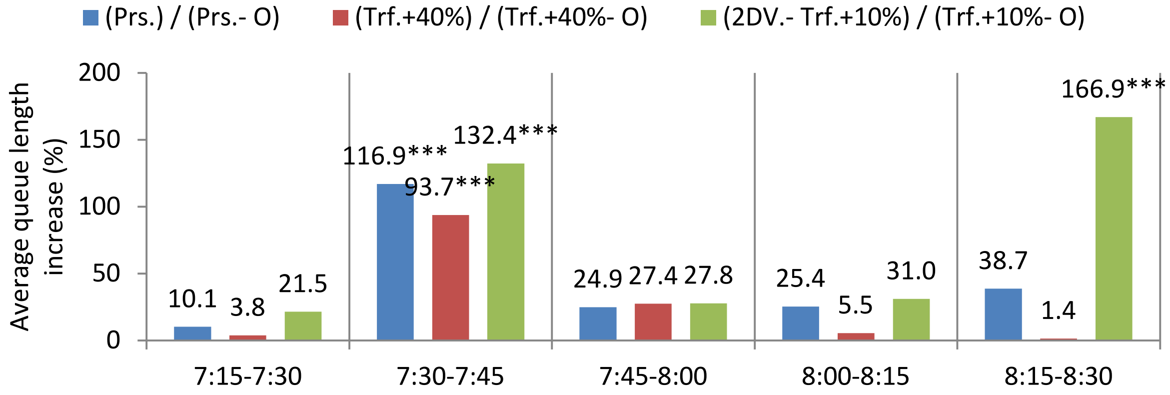

Figure 30 –The reduction ratio of average queue length due to drop-off vehicles behavior

The increase ratio of average queue length due to drop-off vehicles behavior is shown in Figure 30. Concerning to the comparison of case "Prs." versus "Prs.-O", and case "Trf.+40%" versus "Trf.+40%-O", the average queue length doubled significantly for 7:30-7:45 according to drop-off vehicles. The increasing ratio of average queue length in the situation with heavy traffic is lower than in present situation. For the comparison of case "2DV.-Trf.+15%" versus "Trf.+10%-O", the average queue length has significantly risen during 8:15-8:30 as well as 7:30-7:45, which is up to about three times the reference case.

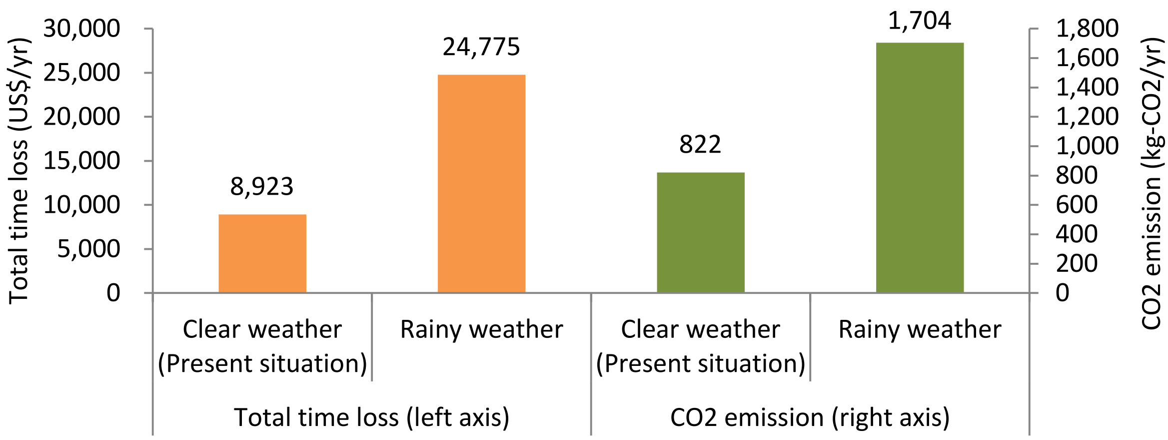

Figure 31 –The social cost derived from drop-off and pick-up vehicles

d. The social costs derived from drop-off and pick-up vehicles

Estimating the time loss through multiplying the total delay time by time value, and taking the difference of the calculated values between "Prs." versus "Prs.-O", and "2DV.- Trf.+10%" versus "Trf.+10%- O" respectively, we figured out annual time loss arouse from drop-off vehicles. These estimated time loss were about 9,000 US$ in the case of clear weather (present situation), and about 25,000 US$ in the case of rainy weather (see Figure 31).

Similarly, estimating CO2 emission with multiplying the traffic volume by CO2 emission factor related to vehicle travel speed, and taking the difference of the calculated values between "Prs." and "Prs.-O", and "2DV.- Trf.+10%" and "Trf.+10%- O" respectively, we figured out annual CO2 emission effected by drop-off vehicles. These estimated CO2 emission were about 820kg in the case of clear weather (present situation), and about 1,700kg in the case of rainy weather. As the result both the time loss and the CO2 emission were enlarged more than twice in the case of rainy weather.

5. CONCLUDION

This study clarified the macroscopic situation of drop-off and pick-up travels by private vehicles through analysing the person-trip data in NKMA, and showed the impacts that drop-off and pick-up vehicle's behaviour had on the road traffic employing traffic simulator.

Drop-off and pick-up travels by private vehicles accounts for 10% of all travels. The principal destination facilities of these travels are schools and railway stations, which account for 70% of all. Concerning to the analysis focusing on the railway station, we found that travel purpose of car passengers being dropped off at stations can differ according to the location of stations. For the analysis on the school, it was shown that the per-school amount of car-related travels vary due to not only the size of the facility but also the attribute of the users of that.

As the result of the case study on School X through observation and traffic simulation, It was shown that for 2-lane-2-way roads with relatively heavy traffic like the target street of the case study, even though accounting for only 2% of the hourly traffic volume, the on-street standing of private vehicles for dropping off possibly have significant negative impacts on the performance of through traffic on both directions of the street. Additionally, we found that simultaneous increase of drop-off travel demand and through traffic volume due to the rainy weather can enlarge the duration and magnitude of the influence on the road traffic. When the influence is a significant problem from the viewpoint of road traffic management, countermeasures against on-street standing of drop-off and pick-up vehicles is necessary from the aspects of facilities improvement, traffic control, and demand management.

Besides, the social cost derived from drop-off vehicles was estimated to be 9,000 US$/year or 820 kg-CO2/year. The amounts of these values are not so impactful. However, it is more important that we showed the order of the social costs using quantitative indicators through empirical and scientific approach. In addition, these costs have caused on the street near only one school for 75 minutes in the morning peak. When the two facts: (1) a lot of educational facilities are located in urban areas; (2) The 60% of Japanese roads are 2-lane-2-way-road like the target street in this study; are taken into account, cumulative social costs derived from drop-off and pick-up vehicles accessing to such facilities might become more impactful amount especially in the case of rainy weather.

Finally, we plan to conduct observations of drop-off and pick-up vehicles arriving at the facilities which are different from schools (e.g. nurseries, kindergartens, cramming schools), and analyse the influence of drop-off and pick-up vehicles' behavior on road traffic through altering the conditions such as road structure, traffic flow, traffic control, and drop-off and pick-up facilities.

Acknowledgment

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