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# Changes in the attitude survey of large vehicle drivers before and after roundabout improvements

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**Abstract**

National highway Route 228 is a main national highway connecting Hakodate City and Esashi Town in Hokkaido, Japan. At the Kaminokuni Town Odome intersection, which is located between these two cities, roundabout operations began in October 2019. The percentage of large vehicles including trucks and semi-trailer trucks at the intersection is as high as approximately 20%. After the intersection had been improved, an actual driving experiment with a semi-trailer truck was conducted to obtain driving behavior data. The speed of the semi-trailer truck in the roundabout was approximately 15 km/h, and a maximum lateral acceleration of 0.17G was recorded. Both before and after the improvement of the intersection, the proficiency level in roundabout traffic rules, driving performance and safety of large vehicle drivers of 10 transportation companies was investigated. As of September in 2019, before the start of the roundabout operation, the proficiency level of large vehicle drivers in roundabout traffic rules was low, and the proficiency level in traffic rules that allow the driver to use the truck apron was only 25%. In October 2020, one year after the start of the roundabout operation, the positive effects of shortening travel time and ease of safety confirmation of intersections were demonstrated.

*Keywords:* Large vehicle drivers, Semi-trailer truck, Driving performance, Roundabout traffic rule

## 1. Introduction

Japan is prone to natural disasters such as earthquakes, tsunamis, typhoons and extreme snowfall. Large-scale traffic congestion and traffic accidents caused by power outages at times of natural disasters have been major social pro blems. Roundabouts are excellent for safety and reducing environmental impact. Furthermore, it can function autonomously even in the event of a power outage during a natural disaster.

In Japan, practical studies on roundabouts have been in full swing since 2009 (1). Based on social and other experiments, the Road Bureau Division of the Ministry of Land, Infrastructure, Transport and Tourism issued a notification, *Desirable Roundabout Structure* (2), which specifies criteria for roundabout planning and design, on

August 8, 2014. The revised *Road Traffic Law* includes a new traffic rule that gives vehicles on the circulatory roadway of a roundabout priority over entering vehicles, and this revision took effect on September 1, 2014 (3). In May 2016, *The Roundabout Manual for Japan 2016* (4) was published by the Japan Society of Traffic Engineers. Roundabout planning, design and basic operation methods have been defined with the objective of introducing roundabouts in Japan. As of March 2023, 155 intersections in 40 prefectures around Japan are operated as roundabouts (5).

In October 2019, a roundabout came into operation on National Highway No. 228 at the Odome intersection in Kaminokuni Town, Hokkaido(6). Since it connects the main national highways, it is characterized by a high percentage of large vehicles of approximately 20% (7). When the geometric structure of the roundabout was investigated, a running experiment in a simulated roundabout as well as a desk examination were conducted to confirm the turning locus (8).

*Report 672* of the TRB's National Cooperative Highway Research Program (NCHRP) NCHRP recommends to determine geometric structures such as ring road width and truck apron structure taking the trajectory of large vehicles at roundabouts into account (9). P. K. Chevuri argued that synthesis review of roundabout design and safety for large vehicles in the United States (10). A. Ruksznis noted that he was often opposed by large vehicle drivers when roundabouts were planned (11). Andrew Torko etal., conducted a risk assessment of large vehicle rollover accidents on roundabouts(12). Eugene R. R. etal., performed various simulations of the driving for large vehicles and demonstrated the structure of truck aprons and splitter islands required for roundabout design (13). However, there are only few studies that evaluate large vehicle drivers at roundabouts. Unfortunately, there are no case studies that have revealed the results of a survey of large vehicle drivers in Japan.

The users of the "Odome intersection" are diverse, including compact cars, ordinary trucks, semi-trailer trucks, vehicles towing utility trailers, snowplows, bicycles, and pedestrians. It can be seen that it is more difficult for a large vehicle such as a semi-trailer truck to turn in a roundabout, because the driving operation width is wider than that of a small vehicle (14), (15). In this paper, we conducted a driving experiment with a semi-trailer truck to obtain basic data on the driving performance and safety of intersections for large vehicle drivers. It has disadvantages for large vehicles such as semi-trailer trucks, such as making it difficult to turn. For this reason, it seems that there are sometimes negative opinions about the introduction of roundabouts from major truck logistics companies. Taking this background into account, we also targeted large vehicle drivers of 10 transportation companies who use the "Odome intersection" on a daily basis to conduct a questionnaire survey on their driving performance, safety and understanding of roundabout traffic rules in 2019 (before and immediately after intersection improvement), and in 2020 (one year after intersection improvement).

Based on the results of a running experiment on semi-trailer trucks and a questionnaire survey of large vehicle drivers, the purpose of this study is to clarify the following.

1) Driving behaviour of semi-trailer truck drivers at a roundabout,
2) Changes in subjective evaluation of driving performance and safety by the driver one year after the roundabout came into operation.

## 2. Study Method

### *2.1. Target roundabout structure*

National highway No. 228 is a main national highway connecting Hakodate City and Esashi Town with a total length of 155.4 km. Kaminokuni Town is located between these cities. The Odome intersection originally was an irregular four-branch intersection with problems from the viewpoint of ease of confirming driver safety, and head-to-head and rear-end collisions occurred frequently. To solve this problem, improvements were made and a roundabout was created (**Fig. 1, Fig. 2**). The improved "Odome intersection" has a roundabout structure with four branches, including two branches for national roads, one branch for prefectural roads, and one branch for town roads.

In October 2019, a roundabout came into operation on National Highway Route 228 at the Odome intersection in Kaminokuni Town, Hokkaido. Since it connects the main national highways, it is characterized by a high percentage of large vehicle use of approximately 20%. It was designed based on *the Roundabout Manual for Japan 2016* published by the Japan Society of Traffic Engineers. When the geometric structure of the roundabout was investigated, a running experiment in a simulated roundabout as well as a desk examination were conducted to confirm the turning locus. When a semi-trailer truck is used as the design vehicle, the recommendation for a roundabout is an outer diameter of 29 m or more in Japan. A snowplow was used to conduct an actual vehicle running experiment involving a semi-trailer truck in a simulated roundabout to measure the velocity and maximum acceleration (lateral direction, vertical direction (front-back direction)) during roundabout driving, while managing the snowy cold region roads in winter. The results of the running experiment are also shown (17).


**Fig. 1**. Old Odome Intersection（Signal Intersection）

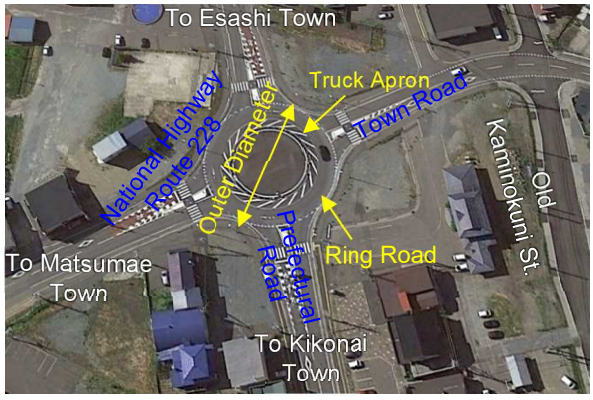


**Fig. 2.** Improved Odome Intersection （Roundabout）

Based on this background, a roundabout improvement project was introduced with the following main objectives.

1) Reduction of traffic accident damage,
2) Speed control at intersections,
3) Reduction of intersection delay time,
4) Introduction of a disaster-resistant structure that works even during a power outage,
5) Demonstration of its functionality as a symbol gate of Kaminokuni Town.

Considering the conditions of intersection traffic volume: approximately 8,000 vehicles/day with a large vehicle percentage of approximately 20%, the basic structure of the roundabout was determined as follows (see **Fig. 2**).

- Design vehicle: Semi-trailer truck (truck length: 16.5 m),
- Outer diameter: 40.0 m,
- Ring road width: 5.5 m,
- Truck Apron width: 2.5 m,
- Central island diameter: 24.0 m,
- Splitter island: Installed,
- Distance between one pedestrian crossing and the next: 5.0 m.

### *2.2. Actual driving test with semi-trailer truck*

The following semi-trailer truck (truck length: 16.5 m) was prepared as the vehicle for the running experiment at a roundabout (**Fig.3**).

- Tractor section : Mitsubishi Super Great (QKG-FP54VDR),
- Trailer section : Nippon Trex Trailer (PFB24102).

The experiment was conducted using two professional drivers with both a towing license and a large vehicle license as the subjects. The outline is as shown in **Table 1**. A drive recorder (CJ-DR450) was installed in the tractor section and the trailer section of the experimental vehicle, and the driving behavior (velocity, lateral acceleration, and vertical acceleration (front-rear acceleration)) was measured. The direction of travel was the main direction of travel of large vehicles on a long-distance trip (1) Esashi-Matsumae, 2) Esashi-Kikonai, 3) Matsumae-Kikonai, both directions). That is, it includes a 90-degree turn, a 180-degree turn, and a 270-degree turn (**Fig.4)**.

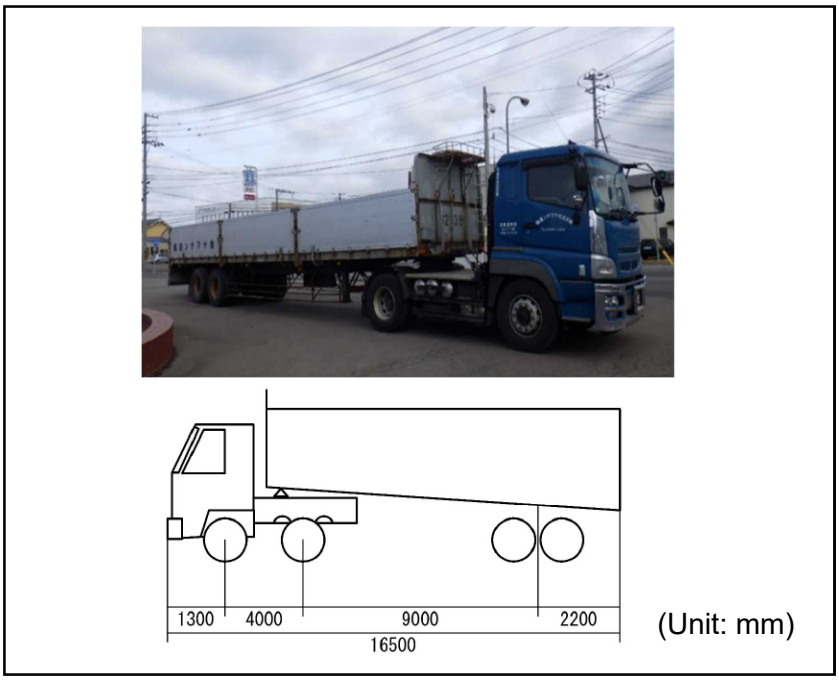


**Fig.3** Semi-trailer truck (Experimental vehicle)

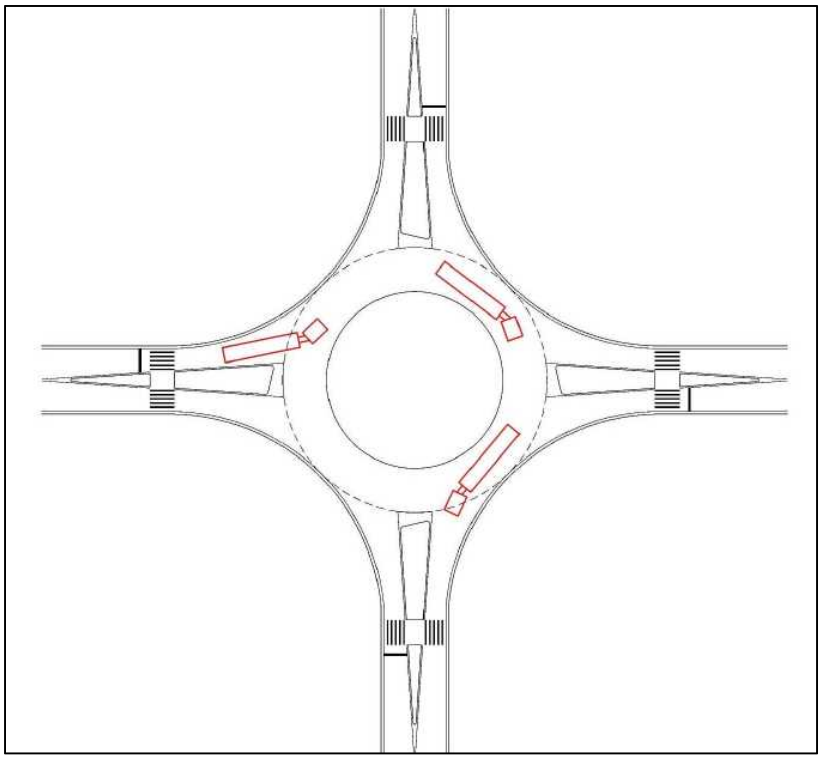

**Fig.4** 270-degree turn of Semi-trailer truck

**Table 1** Outline of driving experiment

| | |
|---|---|
| Experimental Date | Oct. in 2019 |
| Weather | Sunny |
| Road Surface Condition | Dry |
| Subjects | 2 Drivers<br>(With both a towing license and a large vehicle licence) |
| Measuring Item | Velocity / Lateral Acceleration / Verticlal Acceleration<br>(Tractor Section・Trailer Section) |
| Questionnire | Subjective evaluation of Drivability and Safety |
| Direction of Travel | 1：Esashi Town ~ Matsumae Town<br>2：Esashi Town ~ Kikonai Town<br>3：Matsumae Town ~ Kikonai Town |

Regarding the driving behavior of semi-trailer-coupled vehicles, data was obtained from two representative large vehicle drivers. This is because it is difficult to procure large numbers of large vehicle drivers in terms of cost and time.

### *2.3. Qustionnaire survey for heavy vehicle drivers*

A questionnaire survey on the driving performance and safety of large vehicle drivers was conducted in 2019 (both before and immediately after intersection improvement) and 2020 (one year after intersection improvement). The subjects of the survey were professional drivers with both a towing license and a large vehicle license of 10 transportation companies who regularly use the "Odome intersection." In 2019, a total of 114 questionnaires were distributed and 77 responses were collected with a collection rate of 68%. In 2020, a total of 114 questionnaires were distributed and 82 responses were collected with a collection rate of 72%. The outline of the questionnaire survey is shown in **Table 2**. In 2019 and 2020, we targeted large vehicle drivers from 10 same logistics companies, and although not 100%, we targeted at least 90% of the same people. More than 70% of respondents were in their 50s to 60s.

The survey items included the driving performance and safety before and after the improvement of the intersection, and the degree of understanding of the roundabout traffic rules. For example, the truck apron, which is installed on the inner side of the ring road that may be used by a large vehicle (truck, semi-trailer truck, towing vehicle, etc.) that cannot turn only within the width of the ring road. In this roundabout, the truck apron has a tapered height of 2 cm (at the curb) to 5 cm (at the center). The main questions are as follows.

1) What do you know about roundabout traffic rules? (Clockwise movement of traffic inside the ring road, priority on the ring road, turn signal display when entering and exiting from the ring road, use of truck apron by large vehicles, etc.) (Before intersection improvement),
2) Changes in intersection transit time (travel time) before and after the improvement,
3) Changes in ease of safety confirmation before and after the improvement,

Evaluation sheet of intersection travel time and ease of safety confirmation before and after the RAB improvement is shown in **Fig.5**.

**Table 2** Questionnaire survey outline

| Subjects | Occupational driver belonging to a transportation company (with a towing license and a large license) | |
|---|---|---|
| Investigation Period | From Sept. to Oct. in 2019 | From Sept. to Oct. in 2020 |
| Number of Distributions | 114 | 114 |
| Number of Collections | 77 | 82 |
| Collection Rate | 68% | 72% |
| Survey Item | Driver attributes | |
| | Proficiency of RAB Traffic Rule | |
| | Driverability and Safety Before/After Improvement | |

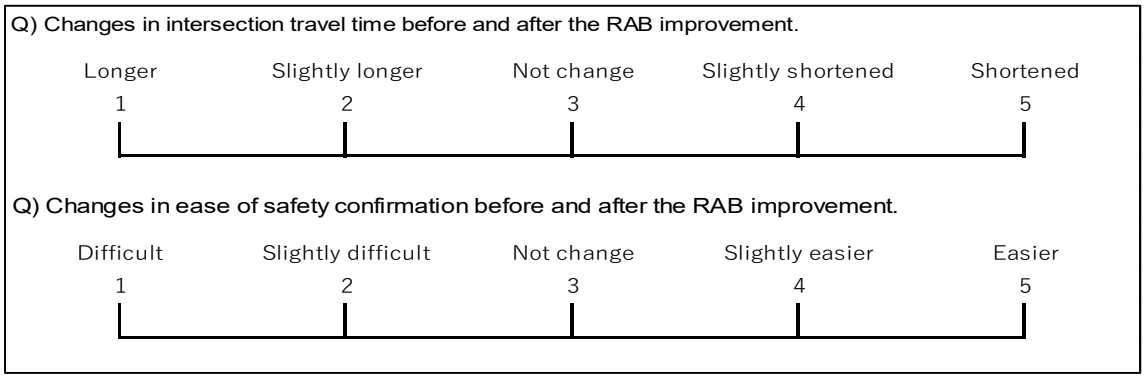


**Figure 5** Evaluation Sheet before and after the RAB improvement

## 3. Study Results

### *3. 1 Driving Behaviors*

A large vehicle driver running experiment on the improved "Odome intersection" was conducted using a semi-trailer truck and a large vehicle driver. The experimental vehicle was equipped with a drive recorder to measure driving behavior. **Figure 6** shows the tractor part and **Figure 7** shows the trailer part as an example of the actual measurement results of velocity, lateral acceleration, and vertical acceleration (front-back acceleration) by the semi-trailer truck when turning 270 degrees.

According to **Fig. 6**, velocity data indicate sufficient deceleration to 10 km/h or less in front of the inflow part, changes around 15 km/h in the ring road part, and increasing to 25 km/h in the outflow part approximately 30 m from the sway line. It increased to 30 km/h. The lateral acceleration increased to approximately 0.17G in the ring road, and increased to 0.17G in the opposite direction at the time of outflow. Regarding the vertical acceleration, the deceleration caused a temporary decrease to approximately 0.15G at the time of inflow, changes from the inflow part to the outflow part at around 0G, and the acceleration from 20 m (distance 90 m in the graph) to approximately 0.13G after the outflow, recorded.

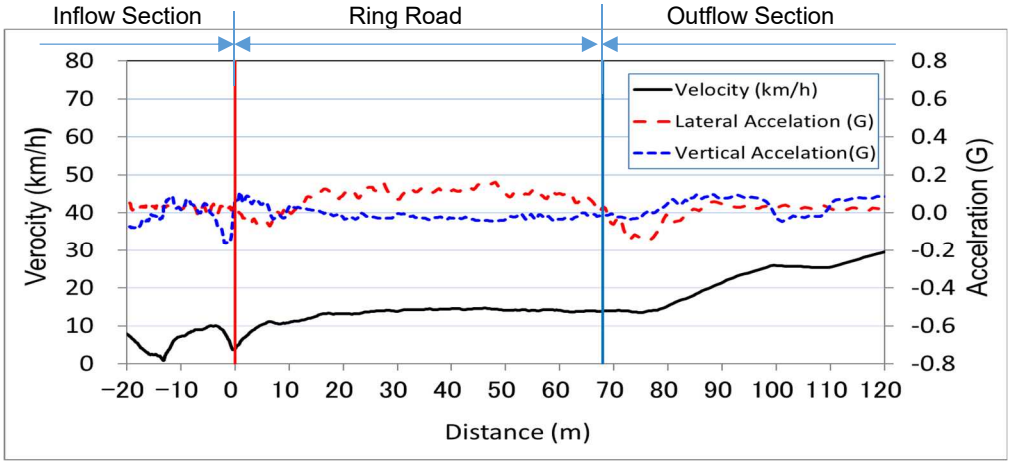


**Fig. 6** Speed/acceleration by semi-trailer truck
(1:Esashi Town to Matsumae Town, 270-degree Turn, Tractor Unit)

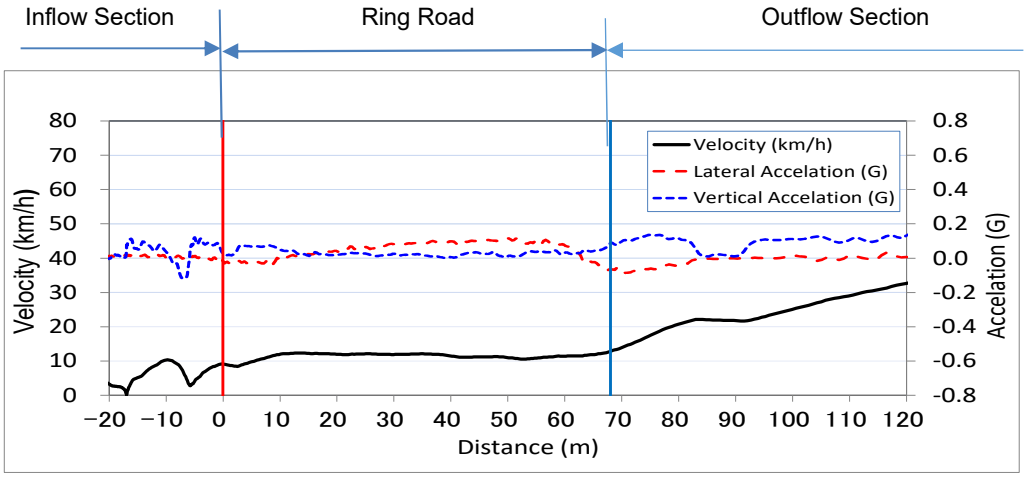


**Fig. 7** Speed / acceleration by semi-trailer truck
（1:Esashi Town to Matsumae Town, 270-degree Turn, Trailor Unit）

Observations before the roundabout improvement (2018) showed that the intersection speed was approximately 50km/h in the Esashi Town to Matsumae Town direction and Esashi Town to Kikonai Town direction, for example.

In response, actual measurements were taken of two subjective drivers after the roundabout was improved. Both of them were traveling at around 15km/h at the roundabout, and were sufficiently slowed down.

### *3.2 Questionnaire results for heavy vehicle drivers*

#### *3.2.1 Roundabout traffic rules*

Before the start of roundabout operation in 2019, we asked 10 large vehicle drivers of transportation companies, “What do you know about roundabout traffic rules?”

1) Movement is clockwise and one-way),
2) Roundabout traffic priority (Roundabout vehicles take priority over inflowing vehicles),
3) Signal when entering and exiting (Vehicles signal when entering and exiting the ring road), and
4) Do you know the individual rules of the truck apron for a large vehicle (The rear wheels of a heavy vehicle may roll over the truck apron when turning at a roundabout)?

The aggregated results are shown in **Fig. 8.**

Fewer than 50% of the respondents said they knew about

1) clockwise movement inside the roundabout,
2) yielding to traffic in the roundabout,
3) signaling at the time of inflow and outflow, and
4) use of the apron by heavy vehicles.

Among these, the lowest awareness was for 4) the traffic rules concerning use of the truck apron by large vehicles. After the start of roundabout operations, large vehicles have accumulated experience of actually using the roundabout, and understanding of the above traffic rules has progressed, with smooth performance of the operation.

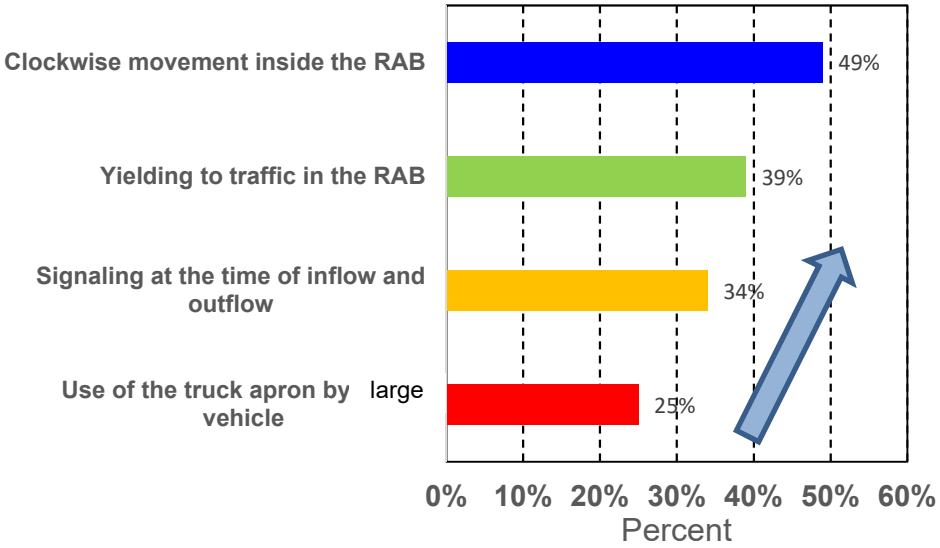


**Fig. 8** Knowledge about roundabout traffic rules

(Total number of responses, N = 77,

Sept. of 2019 survey (before the start of the operation))

*3.2.2 Travel time after improvement (including intersections)*

Next, at the stage of October 2019 (immediately after the start of operation of the improved "Odome intersection") and October 2020 (one year after the start of operation of the improved "Odome intersection"), drivers were asked about their travel time including the improved intersection, in comparison with that before the improvement. The aggregated results are shown in **Fig. 9.**

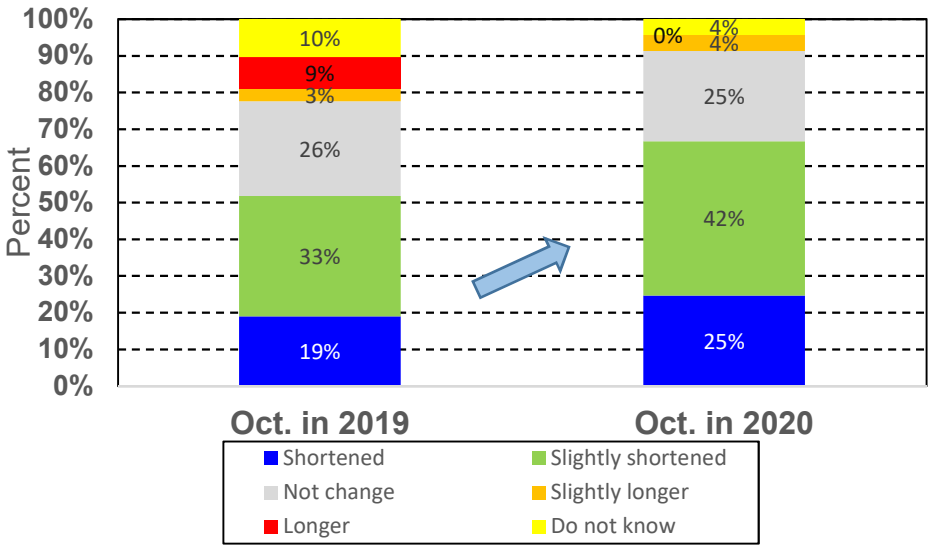


**Fig. 9** Travel time after improvement of the intersection
（Total number of answers, N=58, Survey in Oct. 2019（After RAB operation）,
Total number of answers, N=69, Survey in Oct. 2020）

Of the total number of responses, 52% of large vehicle drivers in Oct. 2019 said travel time had “shortened” or “slightly shortened.” It was found that more than half of the large vehicle drivers felt that travel time including the intersection after its improvement tended to be shortened, and considered the effect of the intersection improvement positively. In Oct. 2020, one year after the opening of the improved “Odome intersection,” 67% of large vehicle drivers answered that driving time had been “shortened” or “slightly shortened.” A statistical test between the 2019 and 2020 data gave a significance level of 1%. Therefore, there was a tendency to shorten travel time.

### *3.2.3 Ease of safety confirmation after improvement*

In addition, the authors asked large vehicle drivers about the ease of checking the safety of the improved “Odome intersection.” “How does it compare with the ‘old Odome intersection’?” The aggregated results are shown in **Fig. 10**. In October 2019, only 18% of the respondents positively considered the ease of safety confirmation as “easier” and “slightly easier,” namely, less than 20%. On the other hand, as many as 54% of the respondents responded negatively with “it became a little difficult” and “it became difficult.” It was found that large vehicle drivers are more likely to think that it has become difficult to confirm safety due to the improvement of the intersection. Therefore, it is presumed that the drivers of large vehicles were driving the turning more carefully immediately after the improvement of the intersection than before the improvement.

In October 2020, one year after the start of the roundabout operation, 35% of the respondents positively considered it to be “easier” and “slightly easier.” On the other hand, 32% of the respondents responded negatively with “it became a little difficult” and “it became difficult.” A statistical test of the 2019 and 2020 data provided a significance level of 1%. In this way, one year after the service came into operation, large vehicle drivers have become accustomed to roundabout driving, and the ease of safety confirmation has been highly evaluated.

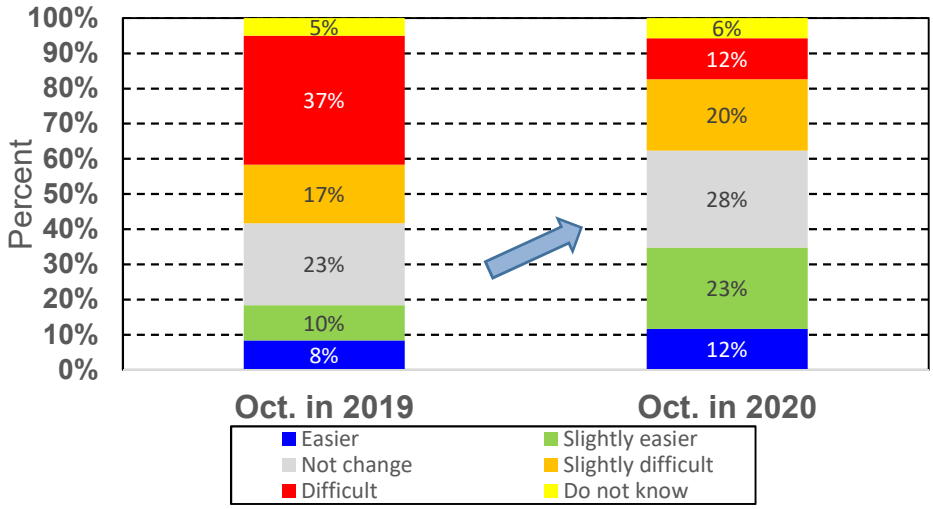


**Fig. 10** Ease of safety confirmation after intersection improvement
（Total number of answers, N=60, Survey in 2019（After RAB operation）,
Total number of answers, N=69, Survey in 2020）

Large vehicle drivers tended to give a negative evaluation, saying that it became difficult to confirm safety at the initial stage of roundabout operation. For these reasons, it is considered necessary to explain the traffic rules and intersection structures more carefully to large vehicle drivers before starting the operation of a roundabout.

### *3.3 Traffic accident occurrence status*

Before the improvement, there were 10 accidents (5 head-on accidents, 5 rear-end collisions) (7 personal injury accidents, 3 property damage accidents) (0.71 accidents/year) over 14 years. After the improvements, there was one accident (one accident involving a meeting) (zero accidents resulting in injury or death, one accident causing damage to property) (0.33 incidents/year) in three years. In this way, after the roundabout improvements, traffic accidents decreased. The number of traffic accidents decreased after a single-lane roundabout improvement, a trend similar to that seen in a German study (18).

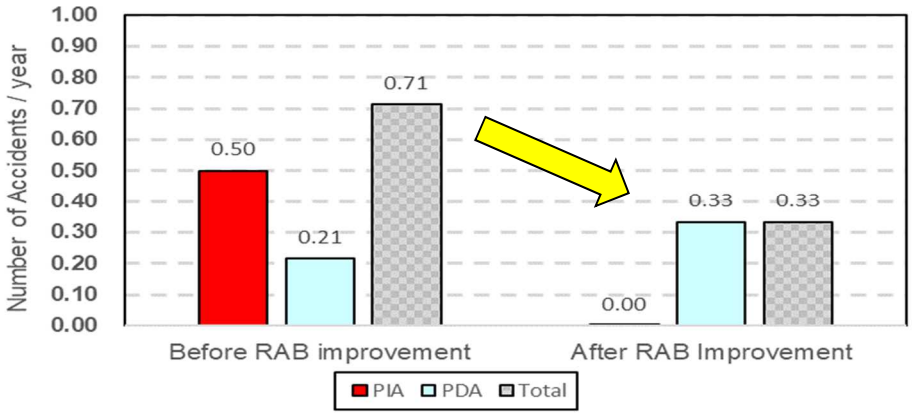


**Fig.11** Number of Accidents per year before/after RAB improvements

(PIA: Personal Injury Accident, PDA: Property Damage Accident)

## 4. REMARKS

At the Kaminokuni Town Odome intersection on National Highway Route 228, we conducted a running test of semi-trailer trucks and a questionnaire survey of 10 large vehicle drivers of transportation companies, both before and after the intersection improvement (traffic light intersection) and one year after the improvement (roundabout intersection). The study and survey revealed the following.

### *4.1 Driving behavior of semi-trailer truck drivers*

A driving experiment was conducted in a roundabout (3 routes, both directions, 2 subjects, 16 runs in total) with a drive recorder attached to a semi-trailer truck, and driving behavior (velocity, lateral acceleration, and vertical acceleration (front-back acceleration)) was measured. The data for 270-degree turns are shown in this paper. Wheels of both the tractor and the trailer of the semi-trailer truck moved at a speed of approximately 15 km/h on the ring road of the roundabout. The lateral acceleration increased up to approximately 0.17G on the ring road, and increased up to approximately 0.17G in the opposite direction when exiting from the roundabout. Based on previous studies, it is considered undesirable for the lateral acceleration to exceed 0.2G, because it is considered to affect the steering wheel. No such data were recorded in the results of this experiment.

As a roundabout geometric structure, it was verified that the outer diameter of the ring road of 40 m is appropriate when the design vehicle is a semi-trailer truck. It should be noted that a certain amount of lateral acceleration is applied when a semi-trailer truck turns at a roundabout, and there is no possibility of rolling over due to overloading.

*4.2 Subjective evaluation by a large vehicle driver*

In 2019 (before and immediately after intersection improvement) and 2020 (one year after intersection improvement), roundabout driving performance, safety, and roundabout usage by large vehicle drivers of 10 transportation companies were evaluated. We asked questions about the degree of understanding of the rules of roundabouts and conducted a questionnaire survey of large vehicle drivers before the start of roundabout operation:

(i) Clockwise rotation on the ring road,

(ii) Priority of ring road traffic,

(iii) Signalling at the time of inflow and outflow, and

(iv) Truck apron driving of large vehicles.

The results showed that fewer than 50% of the respondents knew the main traffic rules of roundabouts. In particular, only a quarter of the respondents knew about the traffic rules for (iv) truck apron driving, which is important for roundabout turning of large vehicles.

In addition, since the signal stop was dismantled due to the roundabout improvement, more than half of the respondents answered that the intersection travel time tends to become shorter than before the improvement in 2019 when the roundabout became operative. Approximately two-thirds of respondents answered that the intersection transit time was shorter in 2020, one year after the opening, and it is presumed that the effect of the roundabout to shorter the transit time was significantly demonstrated.

More than half of the respondents said that the ease of checking the safety of roundabouts tended to be more difficult in 2019 than before the improvement. In 2020, one year after the opening, the number of respondents who said that it tended to be difficult decreased to approximately one-third. One year has passed since the opening, and it seems that large vehicle drivers are getting used to roundabout driving.

Regarding the number of traffic accidents, the number of personal injury accidents and the total number of accidents tended to decrease after the roundabout improvements. The number of property damage accidents almost remained unchanged. In other words, the effect of reducing traffic accident damage, which is a feature of roundabouts, was seen.

*4.3 To improve an understanding of roundabout traffic rules*

Roundabout users are diverse, including small car drivers, large vehicle drivers, motorcycles, bicycles, and pedestrians. Based on previous studies, it is strongly commented that roundabouts are positively evaluated for speed control and accident damage reduction. On the other hand, on national roads that have a trunk line function, the rate of heavy vehicle contamination is high, and at the Kaminokuni Town Odome intersection, approximately 20% of traffic is large vehicle traffic. Based on the results of the questionnaire in this study, it was found that the degree of understanding of roundabout traffic rules tended to be low before the start of operation. In 2019, immediately after the start of operation, large vehicle drivers tended to feel apprehensive about improvement of the roundabout from the viewpoint of ease of safety confirmation. However, in 2020, one year after the opening, positive evaluation of the roundabout, such as “shorter crossing time” and “easier confirmation of safety,” improved.

## 5. CONCLUSION

Regarding the improvement project of the Kaminokuni Town Odome intersection on National Highway Route 228, the Kaminokuni Town public relations magazine, “Public Relations Kaminokuni” published an article about the improvement of the Odome intersection to a roundabout, including the use method, and took measures to disseminate the traffic rules. At the time, the following items were emphasized:

1) Movement on the ring road is clockwise,
2) Priority is given to vehicles inside the ring road,
3) The vehicle must turn while signalling when exiting from the ring road,
4) Large vehicles can turn by stepping on the truck apron.

Roundabout briefings were also held multiple times for residents of Kaminokuni Town, including at the planning stage and when construction started. At the seminars on the roundabout held by the authors, we also carried disseminated information on domestic cases of roundabout maintenance and the introduction of their effects. In addition, a roundabout traffic experience session was also held for approximately 200 local elementary school students and other local residents by road managers and traffic managers (**Photo 1**). By repeating these opportunities, we are convinced that a great effect was obtained from the viewpoint of thoroughly disseminating the roundabout traffic rules to road users including large vehicle drivers.

**Photo 1** Roundabout experience event（Oct. in 2019）

This intersection started operation as a roundabout in October 2019 and has been used steadily since then. It is expected to exert its effects such as the reduction of traffic accident damage, reduction of the environmental impact, resistance to disasters such as power outages, and the function as a symbol gate of the region. Three years after the roundabout improvements, the number of traffic accidents has decreased. There were zero accidents resulting in personal injury and one accident resulting in property damage. The effects of reducing traffic accident damage are already being demonstrated. It is hoped that roundabouts will comply with their own traffic rules and operate safely and correctly. It is also valuable asset that this study was able to grasp changes in the attitude survey of large vehicle drivers toward roundabouts.

The authors will continue to measure the effectiveness of operation of the roundabout.

## Acknowledgements

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