Safety analysis towards introducing roundabouts in Japan

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ABSTRACT

Roundabouts have not yet gained acceptance as an option for reducing traffic fatalities at non-signalized intersections in Japan. The safety study of roundabouts is, therefore, most important for awaking road and traffic administrators from a state of ignorance in Japan. This report shows several recent Japanese activities for evaluating roundabout safety. One activity is comparison study between roundabout and non-signalized right-angled intersection. Japan does not have roundabouts until now. Therefore, user adaptations for roundabouts should be evaluated before their installation. There are many discussions in terms of roundabouts such as whether drivers could make a hook turn in the right turning case (left turn in the US), how to educate the rule to run through the roundabouts and so on. Not having a fully clear answer to this discussion is one reason why it is taking a long time to deploy roundabouts. Virtual Reality is a key issue to provide the driving situation for a new type of intersection, and could resolve these arguments. Two types of intersection (roundabout and non-signalized right-angled intersection) are created to observe driver behavior at the roundabout and compare the safety between the intersections from the viewpoint of deceleration. Thirty-three subjects, including elderly persons were subjected to a running test in this study. Results show many findings, namely, many elderly drivers could make a hook turn in the right-turning case without any introduction of the rule for running roundabouts, the speed at the edge of the roundabout is lower than that at the non-signalized right-angled intersection (approaching from priority road), and the roundabout is safer because of the need to gradually decelerate compared with that in the case of the non-signalized right-angled intersection. The benefit of this study is to show these facts of driving behaviors, which could contribute to the installation of roundabouts in Japan.

The other activity is a comparison study between three types of T-intersection. Each approach of a roundabout looks like a T-intersection. In the left-hand-side traffic rule such as in Japan, the configuration of an approach of a roundabout could be classified into a type of 'T-intersection with a two-way feeder road connected to a one-way main road going to the left (two-way feeder one-way main left)'. There are three types of T-intersection configuration: 'two-way feeder one-way main (TFTM)', 'two-way feeder one-way main left (TFOML)', and 'two-way feeder one-way main right (TFOMR)'. The number of conflicting points of the three types of T-intersection are discussed and compared with the case of a normal four-leg intersection. The driver's behavior while approaching for the feeder road for these types of T-intersection is observed in the real world, and TFOML is revealed as the case with the lowest safety-check load for the drivers when the load is observed as the number of head turnings, time of head turning, and angle of head turning. The results show the considerable advantage of roundabout in terms of safety-check load.

INTRODUCTION

Roundabouts have not yet gained acceptance as an option for reducing traffic fatalities at non-signalized intersections in Japan. The safety study of roundabouts is, therefore, mostly important for awaking road and traffic administrators from a state of ignorance in Japan. This report shows several recent Japanese activities for evaluating roundabout safety.

COMPARISON STUDY BETWEEN ROUNDABOUT AND NON-SIGNALIZED RIGHT-ANGLED INTERSECTION USING VIRTUAL REALITY TECHNIQUE

Background

Roundabout is a type of intersection that has an island in the center. This is commonly used in the US and EU, and contributes to inprove traffic safety. However, it is not installed in Japan. To install the roundabout in Japan, the rule for driving through a roundabout should be checked in terms of whther the Japanese driver can adapt to it or not, and the safety advantage of the roundabout compared with the non-signalized right-angled intersection (hereafter, we call this intersection PSNSI) should be proved.

In this paper, a Mobile Driving Simulator (MDS) is used to conduct the experiment on the use of the roundabout, because there is no roundabout in Japan and it is difficult to construct a real roundabout in the field. MDS is a personal-computerbased simulator utilizing the UC-win/road by Forum 8 Co., Ltd. In MDS, we made two types of intersection, namely roundabout and PSNSI.

The safety benefit of the roundabout could be determined by comparing the driving behavior and impression of subjects for both roundabout and PSNSI. Moreover,



FIGURE 1 Mobile Drive Simulator

desirable traffic control method at the inflow section of the roundabout could be realized by changing the road traffic sign. Furthermore, the subjects were divided into 2 groups: those who were educated on how to drive through a roundabout and those who were not. By comparing the driving behaviors of both groups, the advantage of being educated on how to drive through a roundabout could be evaluated.

Consideration in Establishing Driving Scenario

Before establishing the driving scenario in MDS, the geometry of the intersection was fully discussed by the authors. To compare the driving behaviors in the roundabout and PSNSI, the key variables for checking the difference are many, such as the existence of crossing vehicles or forwarding inflow vehicles, existence of road traffic signs or large fisheye mirrors, road priority and so on. If we use all these variables, the subjects should go through many cases and this will result in long experiments, leading to a lower accuracy of the results because of subjects fatigue. Therefore, four variables were selected in this experiment.

Road Pattern

To evaluate the safety of driving through a roundabout, PSNSI was also used for comparison. To compare both in the right manner, the road geometry such as the width of the inflow section is set the same. To set the geometry of the intersection, a large fisheye mirror should be installed because the sight distance for both corners of the intersection could affect the driving attitude. However, it is difficult to set a large fisheye mirror in MDS because of its size. Therefore, the intersection of PSNSI does not have any disturbances that can decrease the sight distance for crossing roads.

Driving Direction

In the roundabout, the driver should hook turn in the right-turning situation where vehicles have to run on the left side of the road in Japan. Therefore, the running direction is important to evaluate the driving behavior. It is important to check whether the driver could make an appropriate turn or not in a rotating situation. In this experiment, right turn, left turn and go straight are set as the running directions.

Priority

When a driver approaches PSNSI, the driver should decrease his/her speed depending on the road priority. If he/she approaches from a highly prioritized road, he/she does not need to stop at the intersection. However, if he/she approaches from the lower prioritized road, he/she has to stop and confirm the vehicle coming from the crossing road. The difference in the priority makes the driver change his/her driving attitude, and this might lead to a dangerous situation when the driver makes an erroneous action at the intersection. The safety level of the roundabout can be shown by comparing the driving behavior at both intersections.

Road Traffic Sign

In Japan, there does not exist a "yield" sign. Only the "stop" and "crawl" signs exist. "Crawl" is the sign that indicates that drivers could run at a slower speed with no movement when they make a stop action. The speed for "crawl" is almost 5km/h. In the Japanese situation, it is difficult to establish the "yield" sign. A longer time for discussion and modification of traffic laws would be needed. In this study, we made 4 road traffic signs, namely, "stop", "crawl", "yield" and "no sign" (FIGURE 2). Actually, yield is not used in Japan, but we would like to check its appricability. Moreover, it is rather





easy to apply it in MDS compared with making a real road traffic sign.

Driving Scenarios

Considering these factors, we created a driving scenario as shown in TABLE 1. To avoid serial correlation, these scenarios were set randomly and the subject would drive through these scenarios twice in each. This means that subjects would drive through these scenarios 16 times in total. In this experiment, the subjects start 200m away from the intersection and stop at about 50m after passing the intersection.

	Road Pattern		Driving Direction			Priority		Road Traffic Sign			
	PSNSI	RBT	straight	right	left	with	without	none	stop	crawl	yield
1	0		0			0					
2	0			0		0					
3	0		0				0				
4	0				0		0				
5		0	0					0			
6		0		0					0		
7		Ö	Ó							0	
8		0			0						0

TABLE 1 Driving Scenario

Constructed Intersections

FIGURES 3 and 4 show the geometries of both intersections. The diameter of the roundabout is 27m. Thus, this roundabout is classified as a compact roundabout with one lane of circular road and two lanes of connecting road (one lane each for both inflow and outflow).

PSNSI was made to match the size of the intersection with the geometry of the inflow section as the roundabout. These intersections could be made well in MDS, and it could be considered that the subjects could feel the same impressions and it is difficult to distinguish when the subjects drive through the inflow section about 100m away from the intersection.



Outline of Experiment

TABLE 2 shows the outline of the experiment. A feature of this experiment is the use of young and elderly persons as subjects. The reason for utilizing elderly persons is that elderly persons tend to have much difficulty in adapting to the new system. Elderly persons might be surprized to see the roundabout because the roundabout is not installed in Japan. Moreover, elderly persons might not make a hook turn but make a shortcut turn in the right-turning situation.

Date	12/15-12/20, 2009
Place	Akita University
# of Subjects	33
Driving Time	40 minutes

Education on how to drive through a roundabout is important before the full operation when the roundabout is actually installed in Japan. Considering the education method, there are many issues to be resolved, such as what type of information is needed by the driver, how to explain the driving through a roundabout and so on. To understand the effect of education, we divided the subjects into 2 groups in terms of guidance on how to drive through a roundabout. Half of the subjects saw the powerpoint slideshows explaining the driving method. The explanation of the

driving method of the roundabout is shown as follows: 1) one way in the circular lane and drive clockwise, 2) the circular lane has priority. Moreover, these subjects watched the video on running the roundabout as a model case for driving through a roundabout. The explanation time is about 20 minutes. All the subjects including those without education were required to answer the questionnaire concerning their impressions of MDS and of driving through a roundabout in every scenario.

From this experiment, we could obtain many types of data. In this paper, 3 types of data are utilized to evaluate the safety of the roundabout. One is the video data that shows the movement from the aerial view. From this data, we could obtain basic information, such as the driver could run in the correct way (not to make a shortcut-turn in the right-turning situation). Second is the questionnaire data. Transitions of the subject's impressions of driving through the roundabout are analyzed. From this analysis, the impressions of driving through the roundabout could be evaluated, and this result could show the safety advantage of the roundabout compared with PSNSI. Third is the driving behavior of the subjects 50m away from the intersection. By comparing the deceleration characteristic for both roundabout and PSNSI, the safety level of the roundabout could be evaluated. From this data, we could evaluate what type of road traffic sign is appropriate to decrease the speed by comparing the deceleration pattern because we included several road traffic signs.

Rotating Situation at the Roundabout

From the video data, we could find the rotating situation in the roundabout. The subjects lost their way in the circular road and went around while the subjects have to go straight in this scenario. However, there are no problems in going around the circular road many times. At this time, the driver actually lost his/her way while turning around the circular road, but after that, the subjects could check the road traffic sign at the exit corner and could exit from the circular road.

In this case, the driver might not be used to drive through a roundabout, and thus, he would not have enough time to recognize the road traffic sign. In the roundabout, there exist road traffic signs that indicate the destination at the exit corner. Therefore, the driver could exit the road by noting the road traffic sign at the entrance of the exit road whenever the driver forgets the exit road.

User Evaluation by Questionnaire

FIGURE 5 shows the average score by scenario for the handling of MDS. From this figure, there might exist a negative trend in the feeling of handling with the increase in the level of execution. In this study, we had included a trial time so that the driver can get used to the handling of MDS.



FIGURE 5 Impression of Handling the MDS

FIGURE 6 Impression for Safety

However, this result shows that MDS should be improved so that the driver can easily get used to it without for further direction.

FIGURE 6 shows the impression about the safety of intersection. Showing the negative trend of this figure means that there is a fact of easily used to drive the roundabout. Roundabout is not really installed in Japan, but driver could feel safety just only drive this intersection in a MDS. And also, the score of safety is lower than 3.0 (normal) in the roundabout. Therefore, roundabout has certain safety advantage compared to PSNSI.

Safety Evaluation by Driving Behavior

In this section, by focusing on the driving behavior in the approach, the safety level of the intersection is evaluated on the basis of the driving behavior. To understand the driving behavior, the elapsed time is measured from the point 50m away from the intersection to the edge of the intersection in this study. A longer elapsed time indicates that the driver approaches at a slower speed and also the driver might decrease his/her speed too much.

FIGURE 7 shows the average approach time for both intersections. In this figure, PSNSI is divided into 2 groups, namely, priority access or non-priority access, because there might be some difference considering the existence of priority. The driver could pass through the intersection without stopping when he has to go straight with priority access, and he has to stop and check the crossing vehicle if he has to make a right or left turn whenever he has the priority and this leads to a longer elapsed time. Therefore, it could be considered that the elapsed time would differ from each other.



FIGURE 7 Average Elapsed Time by Road Geometry

From this figure, it is found that the elapsed time for the roundabout is almost twice that for PSNSI with priority access. This indicates that the roundabout makes the driver decrease his/her speed too much and shows the safety advantages. However, the elapsed time for PSNSI without priority access is almost the same as that for the roundabout. It was assumed that the elapsed time for PSNSI without priority access is longer than that for the roundabout.

Thus, the elapsed time was divided into two groups, namely young and elderly drivers, and the average was calculated for both groups. FIGURE 8 shows the results of the calculation. Elderly persons have a longer elapsed time than young persons. However, the average elapsed time for the roundabout is shorter than that for PSNSI without priority access. To understand this result, we have to analyze in more detail from the viewpoint of microscopic movements of the vehicle or the speed at the edge of the intersection. From the results mentioned above, by focusing on the small difference between the roundabout and PSNSI without priority access, the variance of these cases is calculated. A larger variance indicates a dangerous situation because

there are many cases of high-speed movement.

FIGURE 9 shows the variance of elapsed time for PSNSI with priority and roundabout for both young and elderly drivers. By comparing the variance, the roundabout has a lower value and this makes the roundabout safer regardless of age group. This indicates that PSNSI causes much difference among individuals whereas the roundabout causes minimal difference in elapsed time. Therefore, the roundabout could establish a safer situation.



Next, we would like to consider the appropriate road traffic sign to control the inflow section of the roundabout. FIGURE 10 shows the average elapsed time depending on the road traffic sign. From this figure, "stop" results in a longer elapsed time, because "stop" indicates that the driver has to stop at this location. This result could be considered natural. Compared with the "yield" and "crawl", the elapsed times are longer than those with no sign and shorter than those with "stop". Thus, these signs have safety advantages compared with situations without any road traffic sign as shown by the decrease in speed while approaching the intersection. Moreover, these signs result in an effective situation because the driver does not need to stop longer when there are no crossing vehicles. In Japan, no "yield" sign exists but the driver might think that "crawl" is almost the same as "yield". Therefore, using the "crawl" sign is one method with safety and efficiency advantages.

Furthermore, by comparing the groups educated on how to drive through a roundabout, the advantage of the roundabout tends to become small (FIGURE 11). It might be considered that there is no need to educate the drivers on how to drive through a roundabout. However, this might be too optimistic situation. It is important to analyze the meaning of this result and consider the appropriate instruction method.



FIGURE 10 Average Time by Road Traffic Sign FIGURE 11 Average Time by Education

HEAD-TURNING ANALYSIS AT T-INTERSECIONS

Analysis Purpose

In this section, the head-turning behavior, to prevent collision, of drivers in the feeder road approach at T-intersections is observed and analyzed.

Intersection Configuration Classification

Each approach of a roundabout looks like a T-intersection. In the left-hand-side traffic rule such as in Japan, the configuration of an approach of a roundabout (RBT) could be classified into a type of 'T-intersection with two-way feeder road connected to a one-way main road going to the left (two-way feeder one-way main left)'. There are three types of T-intersection configuration: 'two-way feeder two-way main (TFTM)', 'two-way feeder one-way main left (TFOML)', and 'two-way feeder one-way main right (TFOMR)' as shown in FIGURE 12. In the case of TFTM, there are two directions of entering



FIGURE 12 Types of T-Intersections

vehicles right-turners (TFTM-R) and left-turners (TFTM-L); otherwise, the available entering movement is restricted to one direction.

# of	types of in	tersections	yielding	coming across	# of conflict points					
Legs			approach	direction	approach	intersection total				
3	1) TETM	1-1) TFTM-R	yes	Left & Right	3	6				
	1) 11 1WI	1-2) TFTM-L	yes	Left	1	0				
	2) TFOMR	ł	yes	Right	2	2				
	3) TFOML		yes	Left	1	1				
4	4) RBT		yes	Left	1	4				
4		5-1) Through	no	Left & Right	5					
	5) 4-legs	5-2) Left turn	yes	Left	1	20				
		5-3) Right turn	yes	Left & Right	5					

TABLE 3 Classification of Intersection Configurations

The numbers of conflicting points of the three types of T-intersection are shown in TABLE 3 and compared with the case of the normal four-leg intersection. The left turners at any type of intersection will always meet only one conflicting movement; otherwise, right turners at T-intersection type 2) TFOMR will meet two, right turners at T-intersection type 1-1) TFTM-R will meet three, and through and right-turning traffic at the normal four-leg intersection type will meet five.

Observation

The approaching driver behavior for the feeder road for these types of T-intersection is observed

in the real world. FIGURE 13 shows the layout of a video camera for the observation of T-intersection type 1) TFTM. VTR 'A' is positioned to check the drivers' head-turning behavior; on the other hand, VTRs 'B' and 'C' are positioned to check the existence of conflicting vehicles approaching from traversing directions. Only one site observation is available for each type of 1)TFTM, 2)TFOMR and 4) RBT with the duration of 2-4 hour observations.

The statistical values as below are summarized with each entering vehicle behavior for each intersection condition: I. head-turning frequency (number of safety checks), II. safety-check duration. The head-turning frequency



FIGURE 13 Observation Example

(I) is defined as the number of right-hand side or left-hand side head-turning behavior of each vehicle's driver from the time the vehicle comes to stop (or the speed decreases) at the stop line to the time it leaves the stop line after performing the safety-check behavior (excluding the times when the driver turns his/her head to the direction of movement); the duration is defined as the safety-check duration (II).

Results and Discussion

Averages and Standard Deviations

FIGURE 14 shows the averages and standard deviations of I. head-turning frequencies and II. safety-check duration for each intersection, each turning direction being considered in terms of the existence of conflicting vehicles approaching from traversing directions.

The averages of both frequencies and durations with conflicting vehicles are higher than those without conflicting vehicles. A correlation between frequencies and durations is found. The more the number of conflicting points, generally the higher the frequencies and duration. Such results indicate that the drivers entering from the feeder road with a large number of conflicting points should pay more attention to avoid colliding with traversing vehicles.

The averages of both frequencies and duration of right turners and left turners show no significant differences in the absence of conflicting vehicles at the intersection 1)TFTM. On the other hand, with conflicting vehicles, right turners (with three conflicting points) pay more attention, particularly to the left, than left turners (with one conflicting point). This is understandable because right turners should pay attention not only to the



FIGURE 14 Frequencies and Duration

traversing vehicles from the right-hand side but also to those from the left-hand side, although left turners should only pay attention to those from the right-hand side.

The left-hand-side frequencies of head turning are higher than the right-hand-side ones at the intersection 2)TFOMR. This is understandable because the traversing vehicles may come only from the left-hand side.

Both the head-turning frequencies and safety-check duration at the intersection 4)RBT are much smaller than those at other intersections, independently from the existence of conflicting vehicles coming from the ring road of the roundabout. This is acceptable because any roundabout has only one conflicting point, and traversing vehicles are always coming only from the right-hand side, and the round shape of the geometry makes the driver easily confirm whether traversing vehicles are coming or not with a rather obtuse angle of head turning than that at other T-intersections. The results show the considerable advantage of the roundabout in terms of safety-check load.

The standard deviations of frequencies and duration are also shown in FIGURE 14. The standard deviations with conflicting vehicles from traversing directions are generally higher than those without conflicting vehicles. In particular, the standard deviations at the intersections 4)RBT are extremely small. It indicates that the smaller number of conflicting points and the effective shape for safety check such as in the case of roundabouts are important to keep low the variance of the safety check-load.

Sight Distances and Angles of Head turning

Sight distances and angles of head turning would be measures to evaluate drivers' safety-check load. The "maximum sight distance" is defined as the distance between the conflicting points between the entering vehicle and traversing vehicle, which is located at the farthest position visible from the entering vehicle at the stop line of the feeder road. The "angle of head turning at the maximum sight distance" is defined as the angle between the straight-through sight line from the entering vehicle at the stop line and the sight line defining the



FIGURE 15 Angle and Arriving Time

maximum sight distance. Any of the angles of head turning is also defined as the angle between the straight-through sight line and the sight line facing the traversing vehicle. Zero angle is defined as when the traversing vehicle is located at the position crossing the through-straight line and stream line of the traversing vehicle, and positive angle is defined when the traversing vehicle is located at right-hand side of the entering driver's eye position (clockwise angle). The arrival time in seconds is calculated as the duration between a point in time when the traversing vehicle is at the location defining the angle of head turning and the point in time of conflicting point at the traversing road speed limit. FIGURE 15 shows the angle of head turning and the arrival time.

FIGURE 16 shows the relationship between the angles of head turning and the arrival time from the spatial point of the maximum sight distance and to the conflicting point between the entering vehicle from the feeder road and the traversing vehicle. 1-1)TFTM-R_a, 1-1)TFTM-R_b, 1-1)TFTM-R_c, 2)TFOMR_d, and 2)TFOMR_e represent the conflicting points with the marks of a, b, c, d, and e shown in FIGURE 12.

The "angle of head turning at the maximum sight distance" at the intersection of 4)RBT is about 20 degrees, those at other types of T-intersection (from 1) to 3)) are approximately 60 degrees instead. The arriving time at the traversing vehicle position of the "maximum sight distance" is about 4.7 seconds at 4)RBT, those at other types of T-intersection (from 1) to 3)) are between about 1.7 to 3.6 seconds. It indicates that the entering drivers at 4)RBT do not need to turn their head so much even when the traversing vehicle on the ring road is located at the position of "maximum sight distance", and the arriving time at the position is relatively long. Such drivers' safety-check load is, therefore, considerably lower than in the other types of T-intersections (from 1) to 3)). These facts would affect the drivers' behavior with extremely small safety-check frequencies and durations.



FIGURE 16 Characteristics of Each T-Intersection

CONCLUSIONS

In this study, several recent Japanese activities for evaluating roundabout safety are shown. From the first analysis, the safety of using the roundabout is evaluated through experiments using MDS to check the applicability of the roundabout as a safety countermeasure. From the result of the experiments, there exists a strange situation wherein subjects make a rotation, but this situation does not cause a higher risk and it is found that the driver could check the road traffic sign many times and select their destination. From the result of user evaluation, the roundabout could bring safer impressions as the driver uses it more. On the basis of driving behavior, it is shown that the roundabout has a certain safety effect compared with PSNSI. It is important to analyze further and show more the safety advantages of the roundabout to realize its adoption in society.

From the second analysis, the approaching driver behavior for the feeder road for these types of T-intersection, namely, TFTM, TFOML and TFOMR, is observed in the real world, and the TFOML is revealed as the case with the lowest safety-check load for the drivers when the

load is observed as the number of head turnings, time of head turning, and angle of head turning. The results show the considerable advantage of the roundabout in terms of safety-check load.

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