

“Strategic Innovation Program (SIP)

– Automated Driving System”

**Survey Research on the Precise Docking of
Next-Generation Transportation Systems
Report**

- SUMMARY -

March 2018

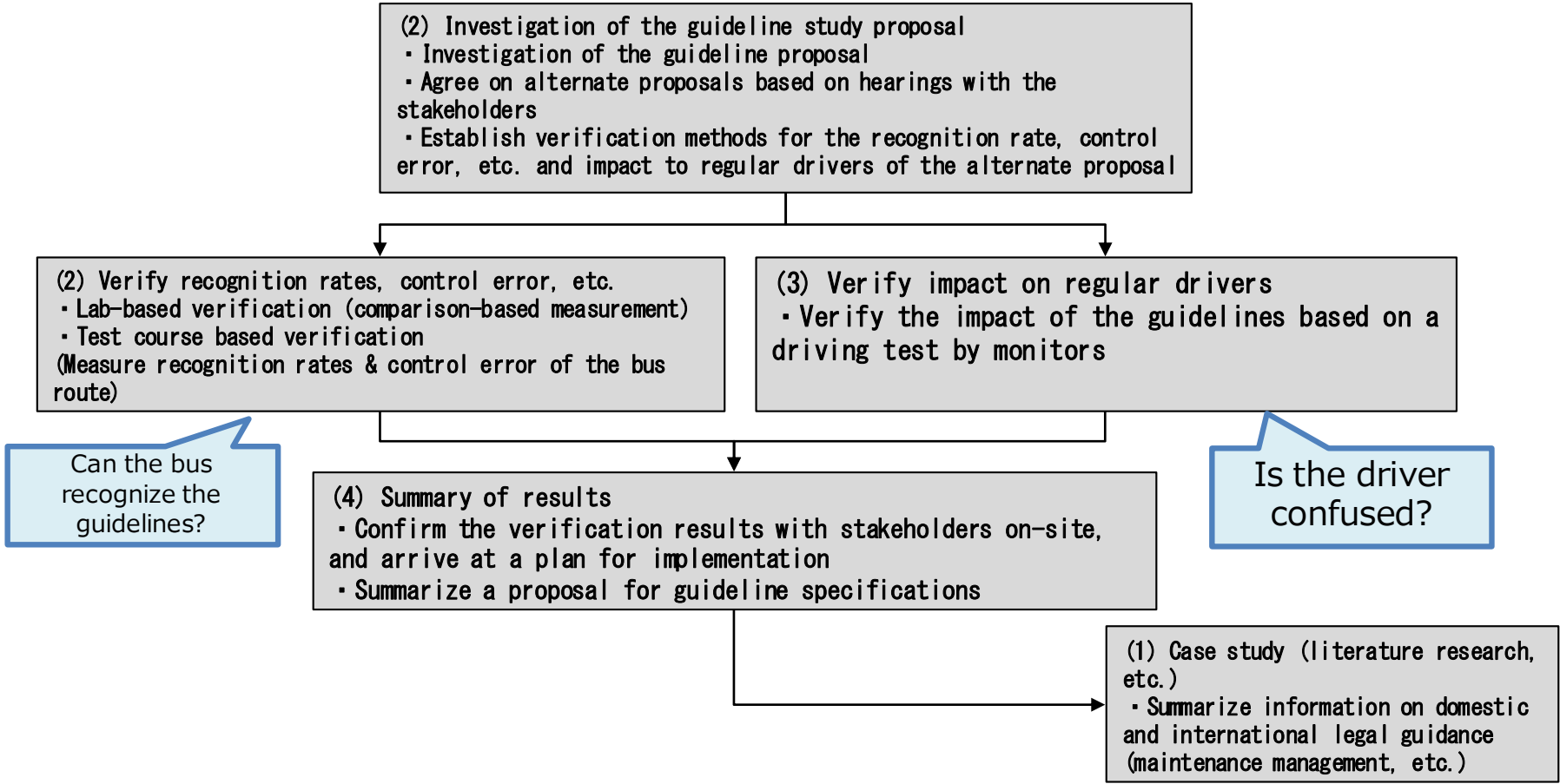
The Institute of Behavioral Sciences

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- 1. Study contents**
- 2. Study on guideline design proposal**
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- 4. Results of guideline selection based on test course experiments**
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- 6. Conclusion**

- Among the control methods being studied for stop precisely at the bus stop (“precise docking”) of ART, or Advanced Rapid Transit, following the path (or guidelines) on the road surface is recognized as the ways of less control errors, but it **still has some issues remained, in case of introducing to the non-busway roads, including such as causing needless common driver confusion.**
- In this study, **the following path of the precise docking readable for the installed camera on ART is investigated, with conducting several demonstration experiments to check its safety.** At the experiments, influence on the driving behavior of general vehicle, and both recognition rates and control errors of the system are investigated at the test course.

1. Study Contents 1-2 Study Flow



2. Investigation of Guideline Design Proposals

2-1 Guideline Design Candidates

The 6 guideline design proposals as follows:

<Proposal 1: White>

- Set as a reference for the experiment.



<Proposal 2: Green>

- A proposal using green to avoid confusion with official traffic lines. Camera recognition was considered in selecting the color.



<Proposal 3: Green - Alt. color>

- A proposal using a different green to proposal 2.



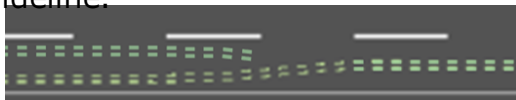
<Proposal 4: Annotation (Bus-use)>

- A proposal which places a note on the road to indicate bus-only use.
- Many proposals can be considered for the contents of the note, its direction, etc.



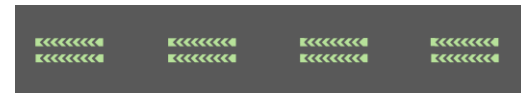
<Proposal 5: Annotation (Line of symmetry)>

- A proposal to add a symmetrical line on the opposite side so that ordinary vehicles are not drawn to the shoulder by the guideline.



<Proposal 6: Arrow lines>

- A proposal using arrow lines to avoid confusion with legal traffic lines.



2 Investigation of Guideline Design Proposals

2-2 State of hearings regarding the guidelines

Based on the below opinions, a verification experiment of the guideline design proposals was carried out, evaluating based on the four points of "legality", "system recognizability", "construction practicality" and "likelihood of confusion by regular drivers"

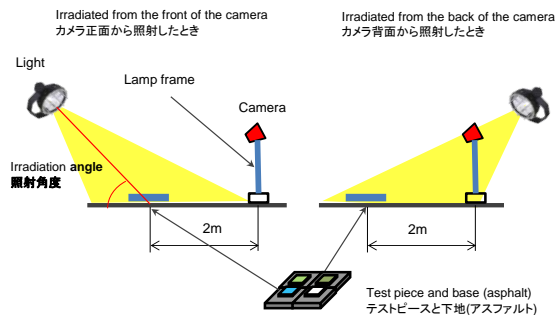
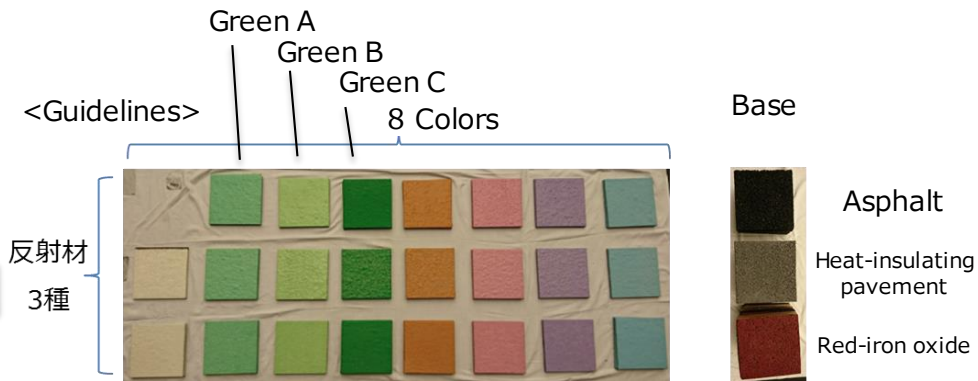
	Key opinions
SIP (Next Metropolis WG, etc.)	<ul style="list-style-type: none">• It is necessary to confirm that there is no negative influence on regular drivers (likelihood of confusion by regular drivers), such as misunderstanding the meaning of the display, or noticeable impact to driving behaviour.• There is a concern that system recognition rates will drop as using green instead of white.• It is desirable to carry out an experiment using proposal 1: white if possible to serve as a reference.• Arrow lines are expected to suppress the tendency of drivers being drawn to the left.• Confirmation should also be made of impact to lane departure notification systems.
National Police Agency	<ul style="list-style-type: none">• Displays that could be confused with legal traffic lines could be contrary to the Road Traffic Law (Legality (or legal compliance)).• It is necessary to use a color aside from the white and yellow used in legal traffic lines, or use a form clearly different than legal traffic lines.
Tokyo Metropolitan Government	<ul style="list-style-type: none">• As a maintainer of the roads, it is necessary to consider the construction and maintenance costs, as well as the construction period (construction practicality) in addition to safety.• If the proposal has the secondary effect of preventing parking near bus stops, it is even better.

3. Results from Laboratory Experiments

- Measure the camera recognition image contrast ratio for the different colors used in the guidelines under various lighting conditions, etc.
- Confirm the "system recognizability" through the experiment results, and thereby decide the guideline color, etc.

■ Combinations of lab experiment conditions

Test Piece	Color	White, Green A, Green B, Green C, Orange, Pink, Purple, Blue	
	Reflecting Material	Glass beads, AWT, Bright Grip	
	Base	Asphalt, red iron oxide, heat-insulating pavement	
Time	Day	Sunshine	Morning, midday, evening (reproduced with lights)
		Light dir.	Front-lit, backlit, angle
		Wetness	Dry, Wet
	Night	Street Lamps	With street lamps, without



3. Results from Laboratory Experiments

Results of Lab Experiments

■ Guideline colors

– While both Green A and B had an image contrast ratio close to White during the day, Green B was measured to have higher image contrast than A.

Green B selected as green candidate

■ Reflecting material

– Glass beads \cong AWT > Bright Grip

* The price of AWT (high function product) is 1.5 times that of glass beads (general purpose)

➢ **A relatively inexpensive general-purpose material can be used**

■ Base material

– Red iron oxide is approximately 0.1 less than asphalt

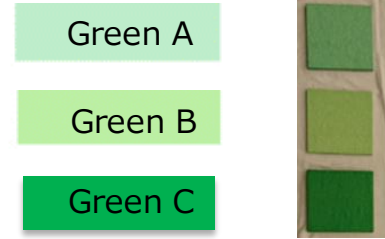
– Even white cannot be recognized by the system on top of heat-insulating pavement

"Asphalt" or "red iron oxide" are desirable as base colors

■ Night

– Green is approximately 0.1 - 0.2 less than white

– Based on the correlation data of street light luminosity and contrast ratio, we plan to determine the recognizable luminosity range.



No	Color	Shape	System Recognizability
P.1	White	Double-dashed line	Best
P.2	Green (Green A)	Double-dashed line	Fair
P.3	Green (Green B)	Double-dashed line	Good
P.4	Green (Green B) Annotated	Double-dashed line	Good
P.5	Green (Green B)	Double-dashed line (Symmetrical)	Good
P.6	Green (Green B)	Arrow line	Bad

3. Results from Laboratory Experiments

Key Results

Basic Performance Evaluation:

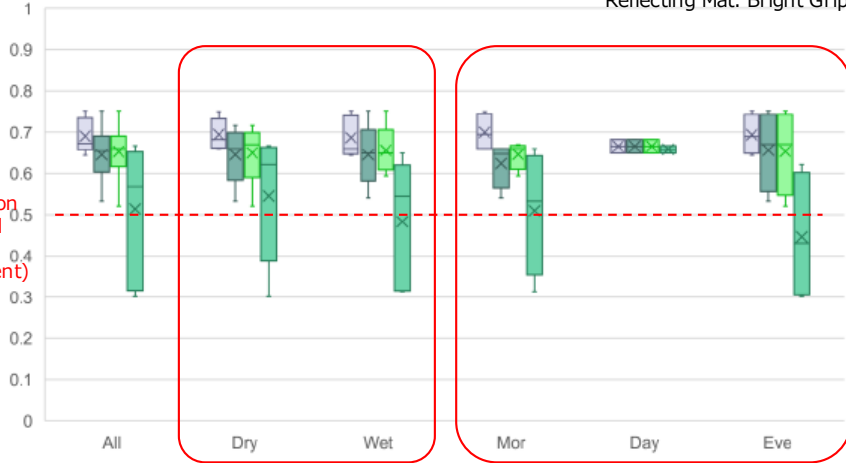
Morning / Sun / Evening + Dry / Wet

Image contrast of candidate colors, grouped

Contrast Ratio

White Green A Green B Green C Base: Asphalt
Reflecting Mat. Bright Grip

System recognition threshold (During experiment)

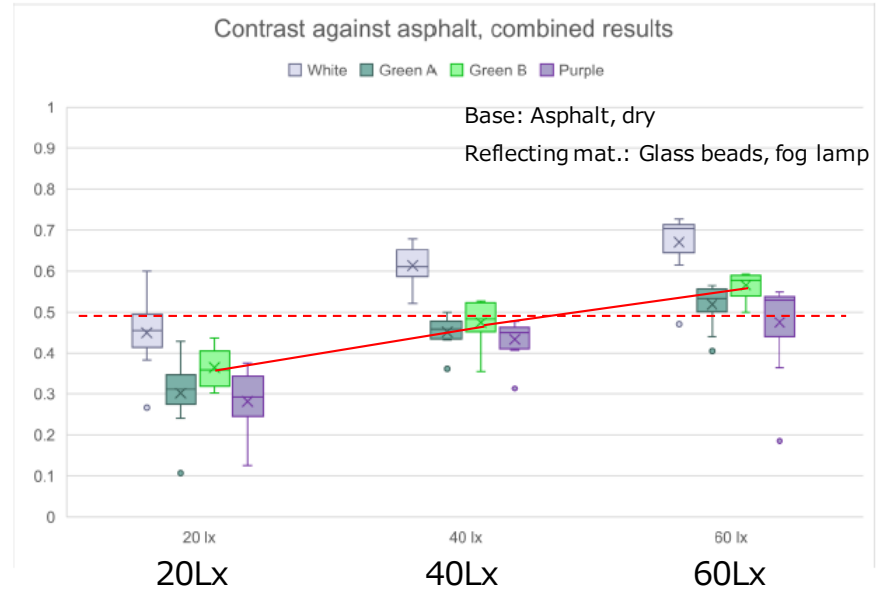


No difference between dry and wet

Performance varies by color under morning or evening sunlight

Nighttime headlight evaluation:

Confirmation of street lamp luminosity



- Contrast ratio improves with greater luminosity
- It is possible system recognition will become impossible based on luminosity

4. Results of Guideline Selection based on Test Course Experiments

Based on the results of 2-4, a test course verification was conducted for the Proposal 1 (reference), Proposal 2 and Proposal 4 guideline designs.

No	Characteristics	Legality	System Recognizability	Construction Practicality
1 reference	White	Bad	Best	Good
2	Green: Green A	Good	Fair	Good
3	Green: Green B	Good	Good	Good
4	Annotated: For Bus	Good	Good	Good
5	Annotated: Symmetrical line	Good	Good	Fair
6	Arrow line	Best	Bad	Fair

5. Verification of Impact on Regular Drivers

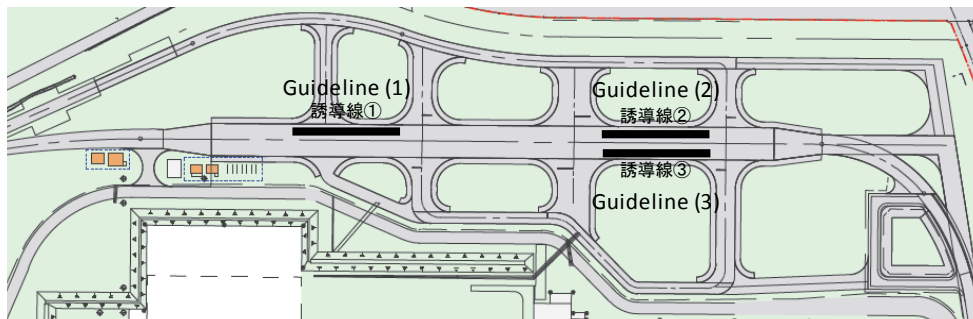
5-1 Overview of Verification Experiment

- Monitors were gathered, and the impact of the guidelines on regular drivers was studied by having the monitors drive on the test course.
- On the final day of the experiment, stakeholders from SIP, the National Police Agency, the Metropolitan Police Department, the Tokyo Metropolitan Government, etc. came to verify the on-site product, conduct a test drive in a passenger vehicle, confirm the precise docking of the bus, and discuss the selection of the guidelines.

■ Verification Test Overview

Dates	Sun., Feb. 11 - Tue., Feb. 13, 2018 (3 days)
Location	General Foundation Corporation Japan Automobile Research Institute (JARI), V2X Urban Proving Ground Course Address: 2530 Karima, Tsukuba-shi, Ibaraki 305-0822
Test Item	Impact study on regular drivers
Subjects	Regular drivers holding driver's licenses (32)
Test Vehicle	Toyota Corolla

■ Overview of the Jari V2X Urban Proving Ground (Tsukuba City)






■ Monitor attributes

	20s	30-50s	Over 60
Male	7	3	6
Female	7	3	6

5. Verification Test on the Impact to Regular Drivers

5-1 Overview of the Verification Test

■ Overview of the guidelines

Proposal Type	Guideline Image	Intention
Proposal 1 (Green)		A proposal using green to avoid confusion with official traffic lines.
Proposal 2 (White)		Proposal set as a reference for the experiment.
Proposal 3 (Green, Annotated)		A proposal which places a note on the road to indicate bus-only use.

Annotated)

■ Proposal 2 (White)



■ Guideline 1 (Green)



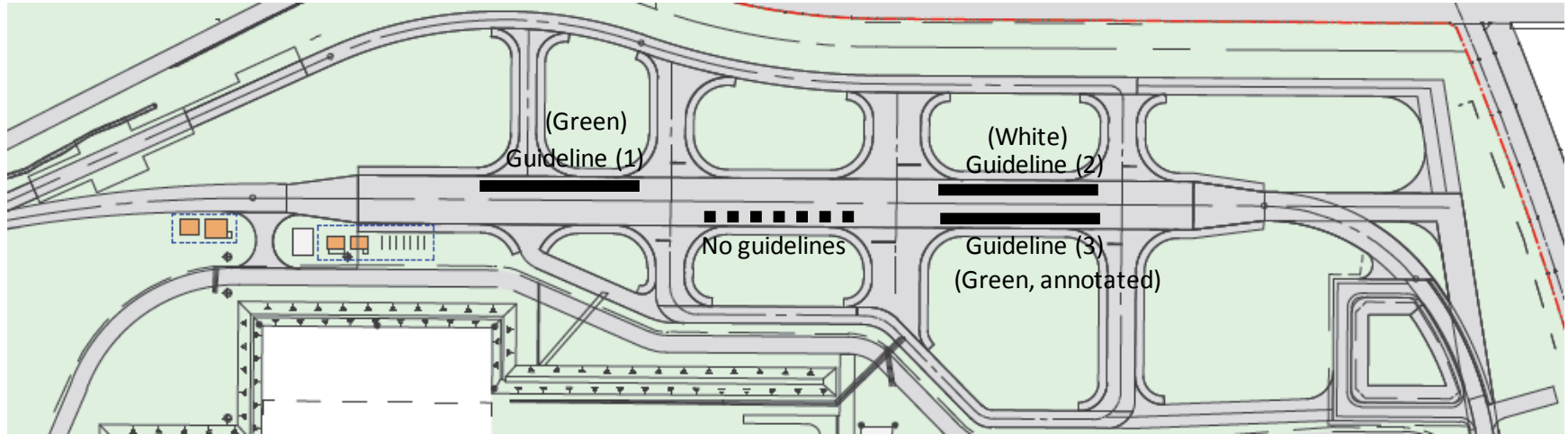
■ Guideline 3 (Green, annotated)



5-1 Overview of the Verification Test

- The monitors were divided into three groups, and each group started from a different guideline.
- Two form-based surveys were conducted with each monitor. The first form-based survey was held after they drove through the first guidelines, and the second survey was held after they drove through all the guidelines.

■ Overview of the JARI V2X Urban Proving Ground Course (Tsukuba City) and the locations of the guidelines



5. Verification Test on the Impact to Regular Drivers

5-1 Overview of the Verification Test

■ Study Items

Events of Concern	Evaluation Item	Measurement Method	Evaluation Standard
1.) Impact to steering wheel handling Ex.: Drifting towards the guidelines, wavering	Position change towards the side	Video images from the side of the car (Video of the white line)	No large change in the driver's line of passage
2.) Impact to braking by the guidelines Ex.: Emergency braking	Change in speed	GPS	No rapid speed reduction
3.) Psychological impact to the driver Ex.: Impression of the guidelines	Impression of the driver	Form-based survey	

* Additionally, in order to eliminate abnormal factors other than the guidelines, a video camera was installed inside the car so that the drivers line of sight and steering wheel handling were recorded.

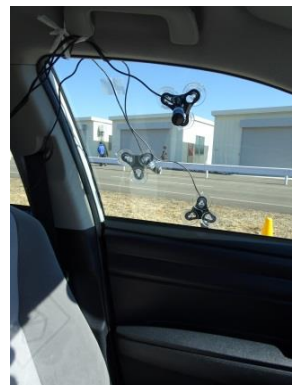
■ Video

(side-mounted)

■ Video (Interior)

■ GPS

■ Car used

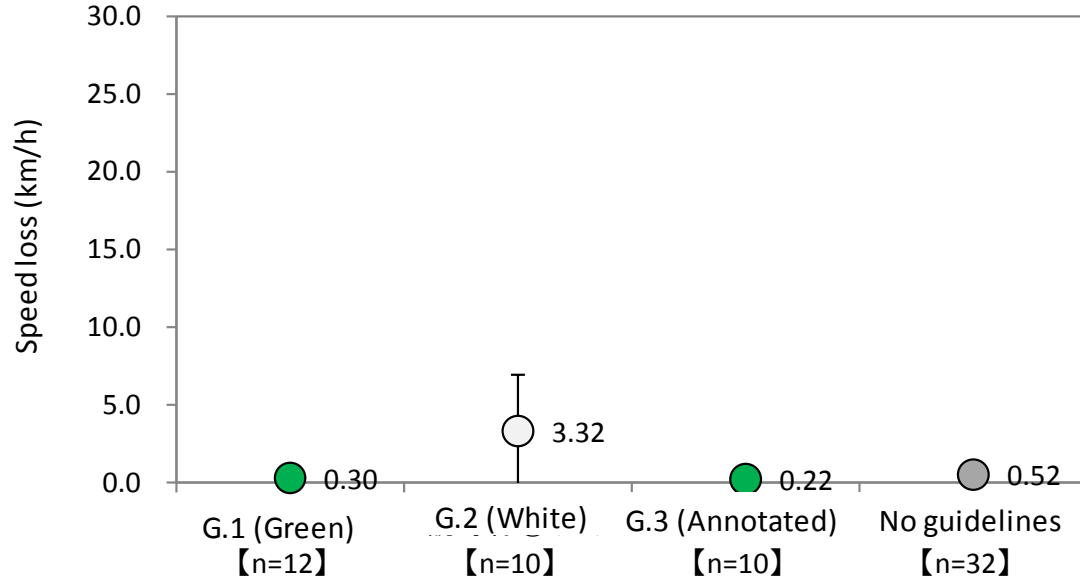


5. Verification Test on the Impact to Regular Drivers

5-2 Impact to Braking

- The speed change observed during the first experience (first sight) of driving through the guidelines is as per the below.
 - Based on the speed at the entry point to the guidelines, and the lowest speed while passing through, no large difference was observed between the different guidelines.

■ Reduction of speed caused by passing through the guidelines (Entry speed - lowest speed while passing through the guidelines)
(standard devia



*Error bar indicates the standard deviation.

5. Verification Test on the Impact to Regular Drivers

5-2 Impact to Braking

- The table to the right demonstrates the change observed in each monitor driver when first driving through the guidelines

- In terms of the largest speed reduction, no drivers had **rapid reduction in speed** on any of the guidelines

* Large reduction in speed defined as 0.3G

- **No large reduction in speed** was observed while driving through "Proposal 1 (Green)", "Proposal 2 (White)", or "Proposal 3 (Annotated)"

- The details of the two monitor drivers who had larger speed reduction are confirmed on the following page

Driving speed of the monitor drivers

No	Guideline Driven	Gen der	Age Range	Max Speed Reduction (G)		Speed (km/h)		Min Speed (km/h)	
				Guideline Area	No Guideline Area	Guideline Area Entrance	No Guideline Area Entrance	Guideline Area	No Guideline Area
1	Guideline 1 (Green)	Male	20s	0.06	0.05	36.5	44.1	1.8	0.1
2				0.06	0.06	35.9	34.3	0.0	0.0
3			30 – 50s	0.04	0.08	45.8	43.3	0.0	0.0
4				0.05	0.08	40.6	41.8	0.1	1.4
5		Over 60	0.04	0.05	25.6	37.1	0.0	0.0	
6			0.02	0.12	40.0	42.2	0.1	0.1	
7		Female	20s	0.01	0.07	46.4	41.4	0.0	0.0
8				0.02	0.04	35.8	33.7	0.0	0.0
9			30 – 50s	0.05	0.07	40.9	50.8	0.2	0.2
10				0.09	0.07	39.5	40.7	1.4	0.2
11		Over 60	0.11	0.07	33.6	42.0	0.0	1.1	
12			0.05	0.11	36.5	36.6	0.0	0.2	
13		20s	0.11	0.03	39.0	38.3	2.6	0.2	
14			0.02	0.05	35.7	39.1	0.0	0.3	
15	Male	30 – 50s	0.11	0.07	29.9	35.7	9.3	0.7	
16	Guideline 2 (White)	Over 60	0.09	0.08	37.6	38.2	5.1	3.2	
17			0.05	0.04	35.9	38.4	0.0	0.0	
18	20s	0.10	0.09	35.6	38.7	6.5	0.8		
19		0.09	0.04	33.0	37.5	8.0	0.1		
20	Female	30 – 50s	0.09	0.07	34.9	39.4	1.5	1.1	
21		Over 60	0.07	0.09	39.4	41.5	0.1	1.5	
22	20s	0.06	0.06	41.0	40.0	0.0	0.6		
23		0.07	0.06	30.5	43.1	0.0	0.5		
24	Male	20s	0.06	0.08	33.3	42.3	0.0	2.2	
25		30 – 50s	0.07	0.05	36.9	37.9	1.5	0.0	
26	Guideline 3 (Annotated)	Over 60	0.01	0.08	40.7	46.0	0.1	0.6	
27			0.05	0.07	38.3	44.2	0.3	0.4	
28	Female	20s	0.07	0.12	36.6	50.7	0.0	0.1	
29		0.06	0.03	37.0	49.9	0.0	0.0		
30	30 – 50s	0.01	0.04	29.4	38.3	0.0	0.0		
31		0.09	0.05	34.5	38.5	0.0	0.0		
32	Over 60	0.03	0.08	42.9	44.8	0.4	0.6		
				0.30	0.30				

The speed distribution of subjects with a large change in speed can be confirmed on the following page.

Rapid drop in speed Defined as 0.3G

5. Verification Test on the Impact to Regular Drivers

5-2 Impact to Braking

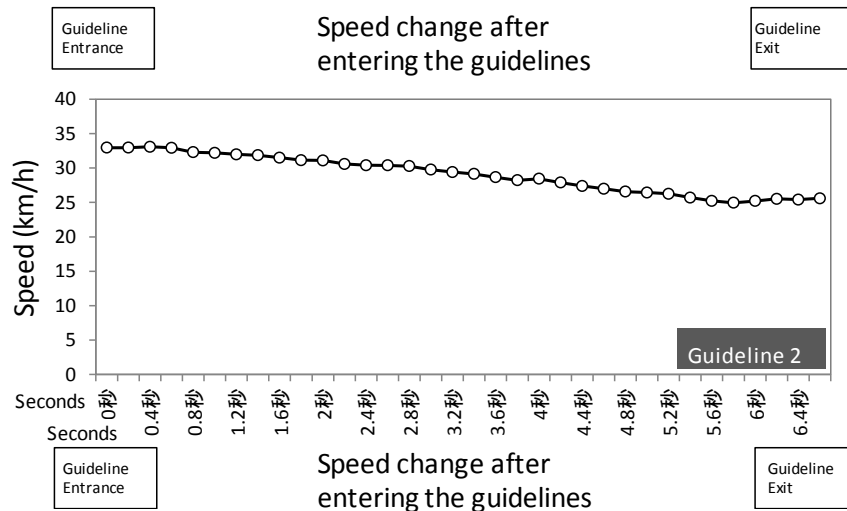
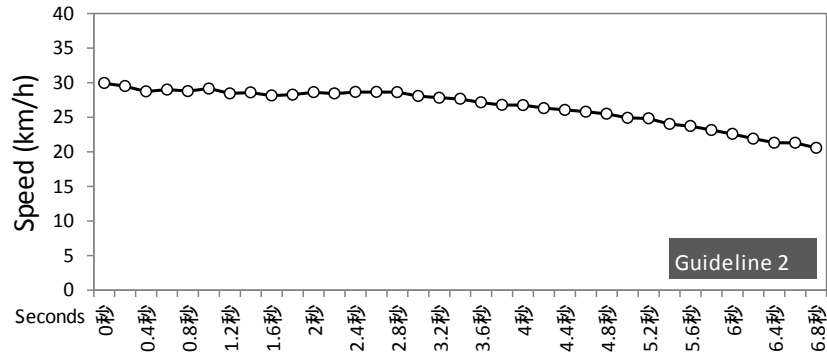
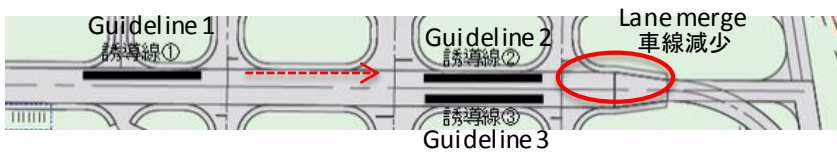
<Examples of speed changes>

1.) Monitor 15: Speed reduction: 9.3 km/h
Acceleration 0.04G (Guideline 2 (White))

- Speed gradually decreased after entering the guideline area, it is believed the accelerator was lightened.
- The monitor answered "I did not brake" in the post drive survey.

2.) Monitor 19: Speed loss 8.0km/h
(Guideline 2 (White))

- Speed gradually decreased after entering the guideline area, it is believed the accelerator was lightened.
- In the post-drive survey, the monitor answered, "I did not slow down due to the guidelines, but rather because the lanes were being reduced ahead."

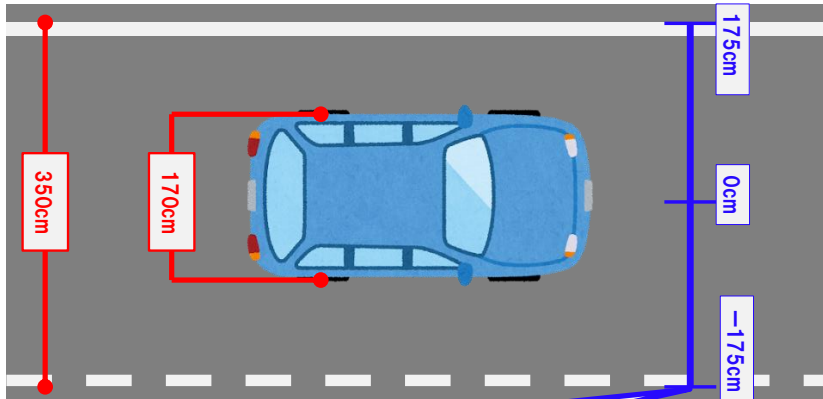


5. Verification Test on the Impact to Regular Drivers

5-3 Impact to Steering

- The following “**entrance driving position**” observations were made when driving through the first guidelines
- No major differences were observed between the guidelines, and there was overall a right-drifting tendency.
- No major differences were observed in the guideline and no guideline areas.

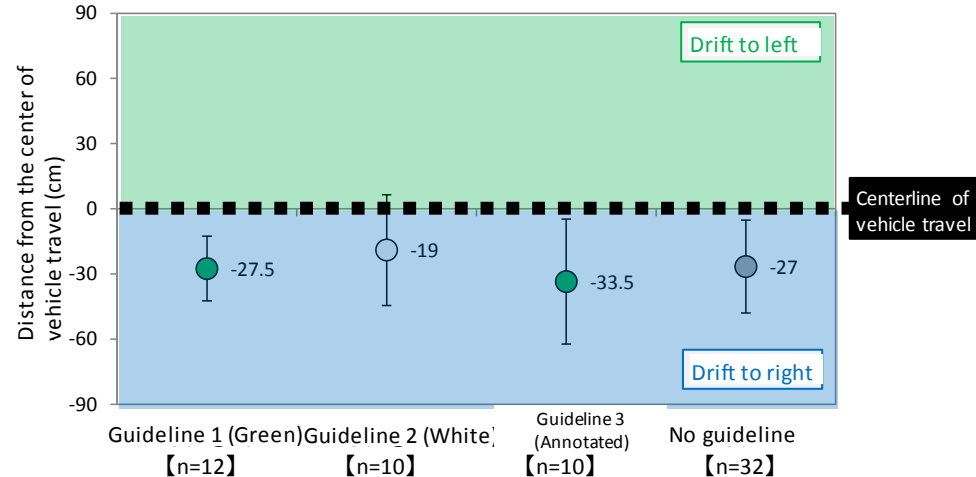
■ Vehicle driving position



Definition of travel position

- The “vehicle center” is used
- Left drift is “+”, right drift is “-”

■ Vehicle driving position (entrance area) (standard deviation)



* Error bar indicates standard deviation.

5. Verification Test on the Impact to Regular Drivers

5-3 Impact to Steering

- The table to the right demonstrates the change observed in each monitor driver when first driving through the guidelines
- The lateral change was approximately 20cm for each guideline
- A large change was observed in drivers for "Guideline 2" and "Guideline 3", and their driving details are confirmed on the following page

■ Lateral changes per monitor

No	Guideline Driven	Gender	Age Range	Distance from travel path center (cm) * "+" is left drift, "-" is right drift.		Lateral change (cm)	
				Guideline Area Entrance (*)	No Guideline Area Entrance (*)	Guideline Area Entrance (*)	No Guideline Area Entrance (*)
1	Guideline 1	Male	20s	-25.00	0.00	5.00	5.00
2				-25.00	-30.00	5.00	10.00
3				-30.00	-35.00	15.00	0.00
4			30 - 50s	-10.00	-15.00	0.00	5.00
5				-10.00	-20.00	5.00	10.00
6				-30.00	-45.00	15.00	5.00
7		Female	20s	-20.00	-35.00	15.00	10.00
8				-40.00	-20.00	5.00	10.00
9				-25.00	-40.00	5.00	5.00
10			30 - 50s	-55.00	-40.00	10.00	5.00
11				-50.00	-35.00	5.00	10.00
12				60歳代以上	-10.00	-20.00	10.00
13	Guideline 2	Male	20s	-20.00	-60.00	5.00	5.00
14				-5.00	0.00	10.00	5.00
15			30 - 50s	30.00	0.00	15.00	0.00
16		Over 60	-25.00	-55.00	10.00	15.00	
17			-40.00	-5.00	10.00	10.00	
18			-10.00	-5.00	50.00	15.00	
19	Guideline 3	Female	30 - 50s	-20.00	-35.00	10.00	5.00
20				-20.00	-25.00	0.00	10.00
21		Over 60	-10.00	-35.00	5.00	25.00	
22			-70.00	-65.00	15.00	15.00	
23	Guideline 3	Male	20s	-30.00	-5.00	20.00	20.00
24				0.00	5.00	15.00	15.00
25			30歳代~50歳代	-15.00	-15.00	5.00	10.00
26		60歳代以上	-70.00	-35.00	30.00	5.00	
27			-85.00	-70.00	0.00	10.00	
28			-10.00	-5.00	10.00	0.00	
29	Female	20s	-40.00	-30.00	15.00	5.00	
30			30 - 50s	-35.00	-20.00	20.00	5.00
31		Over 60	-50.00	-65.00	30.00	25.00	
32			0.00	10.00	10.00	10.00	

The travel path through the guidelines is confirmed for monitors with large lateral movements.

5. Verification Test on the Impact to Regular Drivers

5-3 Impact to Steering

1.) Monitor 18: Lateral movement 50cm (Guideline 2 (White))

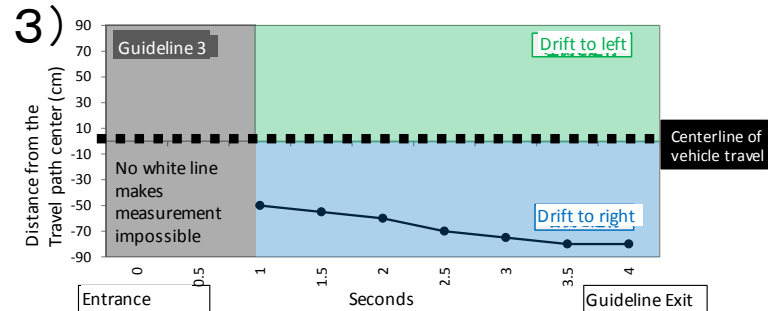
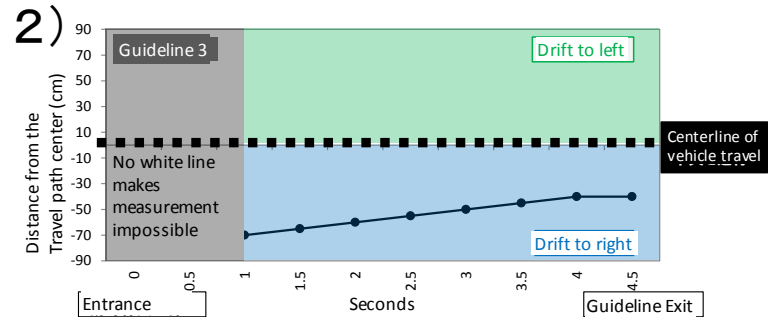
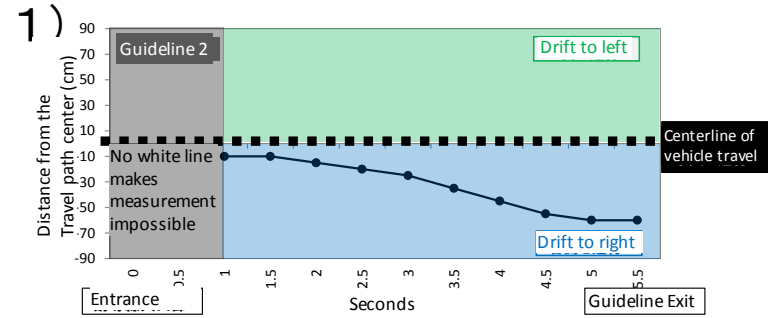
- Drifted to the right in the guideline area.
- In the form-based survey, the monitor answered, "I was uneasy because I didn't know what kind of line it was," and "I moved to the right to avoid driving on the line."

2.) Monitor 26: Lateral movement 30cm (Guideline 3 (Annotated))

- Entered on the right side and moved to the left.
* Also drove on the right for other guidelines.
- In the form based survey, the monitor answered, "I thought it was a bus lane, and if I saw it while driving on regular roads, I would not use that lane."

3.) Monitor 31: Lateral movement 30cm (Guideline 3 (Annotated))

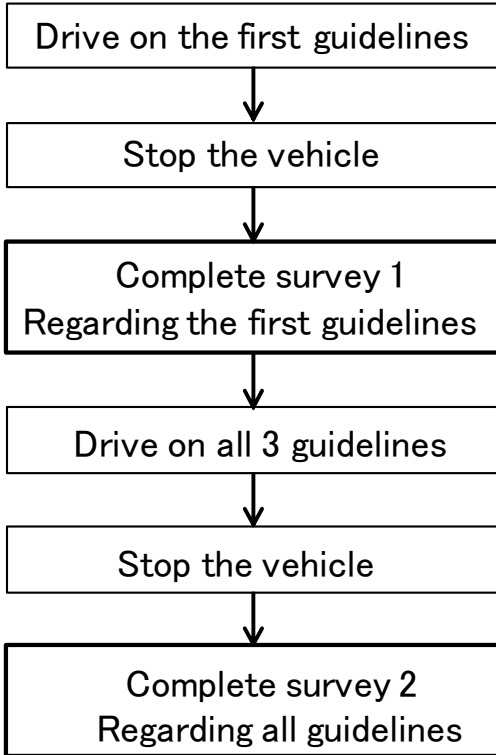
- Drove on the right as far as the lane allowed in the guideline areas.



5. Verification Test on the Impact to Regular Drivers

5-3 Form based survey

■ Flow of the form based survey during the test



■ Contents of the survey

Category	Question No.	Question Contents	
Form based survey 1	Q1	Did you notice anything in the driving area? ▪ If they noticed the guidelines -> Q2 ▪ If they did not notice the guidelines -> Q6	
	Q2	Recognition of the guidelines	
	Q3	Intention while driving through the guidelines	
	Q4	Vehicle handling while driving through the guidelines	
	Q5	Impact to driving from the guidelines	
	Q6	(Show the guidelines) Did you notice the guidelines? ▪ If they noticed -> Q7 ▪ If they did not notice -> Q10	
	Q7~9	(Same as Q2-4)	
	Q10	(Same as Q5)	
	Form based survey 2	Q1	▪ Gender ▪ Age range ▪ Driving frequency and history
		Q2	(Show the guidelines) Did you notice each guideline?
Q3		Recognition of guidelines	
Q4		Intention while driving through the guidelines	
Q5		Vehicle handling while driving through the guidelines	
Q6		Impact to driving from the guidelines	

5. Verification Test on the Impact to Regular Drivers

5-2 Form based survey

■ Prominent answers from the first-drive survey

- No monitors recognized Guideline 1 (Green) as a bus related marking. One monitor was uneasy because there was no explanation (1 person).
- Some monitors recognized Guideline 2 (White) as an indication to move to the left (3 people). There were also monitors who moved to the right to avoid driving on the line (2 people).
- There were monitors who saw the “For Bus” marking of Guideline 3 (Annotated) and recognized the markings as a bus lane (6 people). Among them, there were monitors who answered they would not normally drive in that lane (4 people).

■ Prominent answers from survey 2 (second drive)

- Among the monitors who first drove on Guideline 3 (Annotated), there were monitors who correctly recognized Guideline 1 and 2 as “Being related to buses, and not for me.”
- There was one monitor who saw the “For Bus” marking for Guideline 3 (Annotated) during their second drive, and changed lanes because they recognized it as being “Bus Lane.”

-> The guidelines are interpreted in different ways based on whether or not they are annotated. Public awareness raising activities are therefore necessary to avoid driver confusion.

6. Summary of Verification Test Results on the Test Course

■ Results of the verification test

No.	Characteristics	Legality	System Recognizability	Construction Practicality	Likelihood of Confusion
Guideline 1	Green: Green B	Good	Good	Good	Good
Guideline 2	White	Bad	Best	Good	Good
Guideline 3	Annotated: For Bus	Good	Good	Good	Fair

■ Key opinions from the on-site observation

- In this experiment, it was confirmed that “Green” **has no issues in being confused with legal traffic lines.** (Overall)
- As a color, there are no issues with “Green.” (National Police Agency)
- **Easy-to-understand public awareness** raising activities are necessary to ensure the guidelines are recognized as being for buses. (Overall)
- (In addition to the above) It is also important to ensure the “kindness” expressed will be understood. (Wheelchair user)
- Further considerations are needed regarding **the installation, system of maintenance & management**, and interference with existing road markings (National Police Agency, Bureau of Urban Development)
- Regarding recognizability at night and robustness, investigations are required into the actual environment of use. (Manufacturer)

■ Issues

- <During implementation>
 - Management of the cost of the guidelines maintenance
- <Future issues>
 - 1) Clarification of system for the installation and maintenance
 - 2) Comprehensive publicities and verification on actual roads to confirm the robustness

<Regarding the maintenance & management of guidelines>

Case	Contents
Rouen (TEOR)	<ul style="list-style-type: none">• Guidelines are repainted once every two years (once every year for lanes shared with regular traffic).• Removal of fallen leaves and measures for snow are necessary. Drivers provide notices on areas that need fallen leaf removal.• The recognition rate of the camera decreases when the water accumulates in the furrows, so asphalt roads are repaved once every 6 years. (Once every 10 years for regular roads)
Construction Operators	<ul style="list-style-type: none">• In the preparation for the verification test, one line could be painted every 2-3 hours. (In the case of simple construction using Grouncial Sheets)• Setting the position is important at the time of actual construction.• As one example, the method of using stencils in the painting, similar to those used for automobile traffic arrows, can be considered. The stencils themselves are extremely low cost, and if maintenance is carried out before the existing markings disappear, they can be set over the existing markings, thus avoiding the need to determine the proper location.