Large scale field operation test on automated driving systems
for Strategic Innovation Promotion Program(SIP)

The research on Pedestrian Collision Reduction

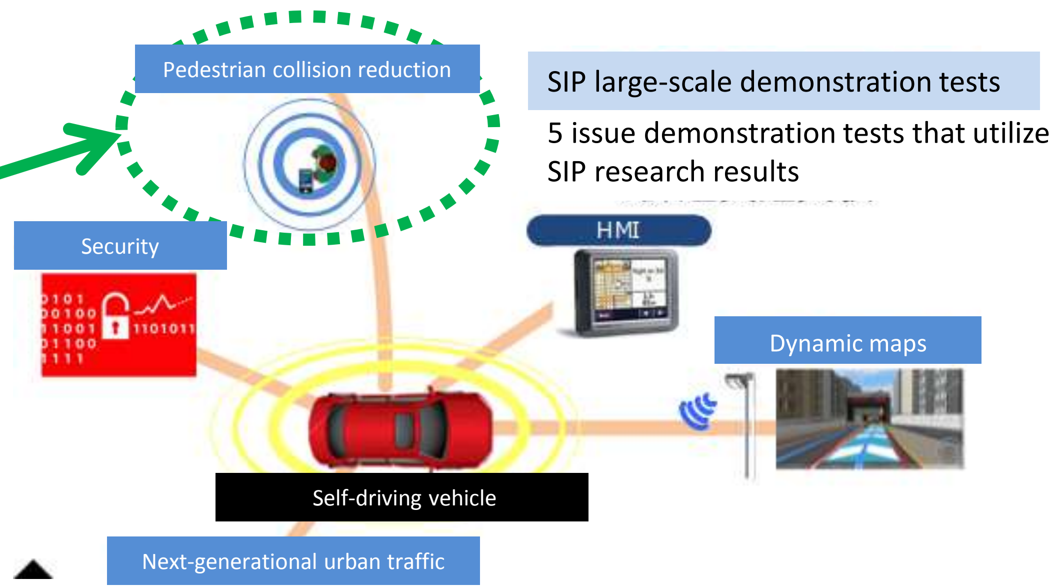
FY 2017 report summary

March 2018
Nippon Koei Co., Ltd.

1. Research overview

R&D overview	➢ **Conduct operation tests on “pedestrian collision reduction”** in connection with SIP autonomous driving systems / large-scale test demonstrations. ➢ Conduct testing on mutual alert functionality of “vehicle-to-pedestrian communication technologies (V2P)” and “high precision pedestrian positioning technologies / action prediction technologies,” **incorporating the technology in actual traffic environments and demonstrating the effectiveness at lowering pedestrian accidents.** ➢ **FY 2017 objective: To conduct functionality verification in a variety of settings and determine aspects of improvement in preparation for the next fiscal year.** ➢ **FY 2018 objective: To conduct demonstrations with general test-users and assess the effect on lowering pedestrian accidents in real traffic environments, determining issues with practical implementation.**
Research period	➢ FY 2017 winter pre-verification and FY 2018 autumn main demonstration are the control points of research. ➢ Maintain close collaboration with developers and remain flexible regarding schedule.

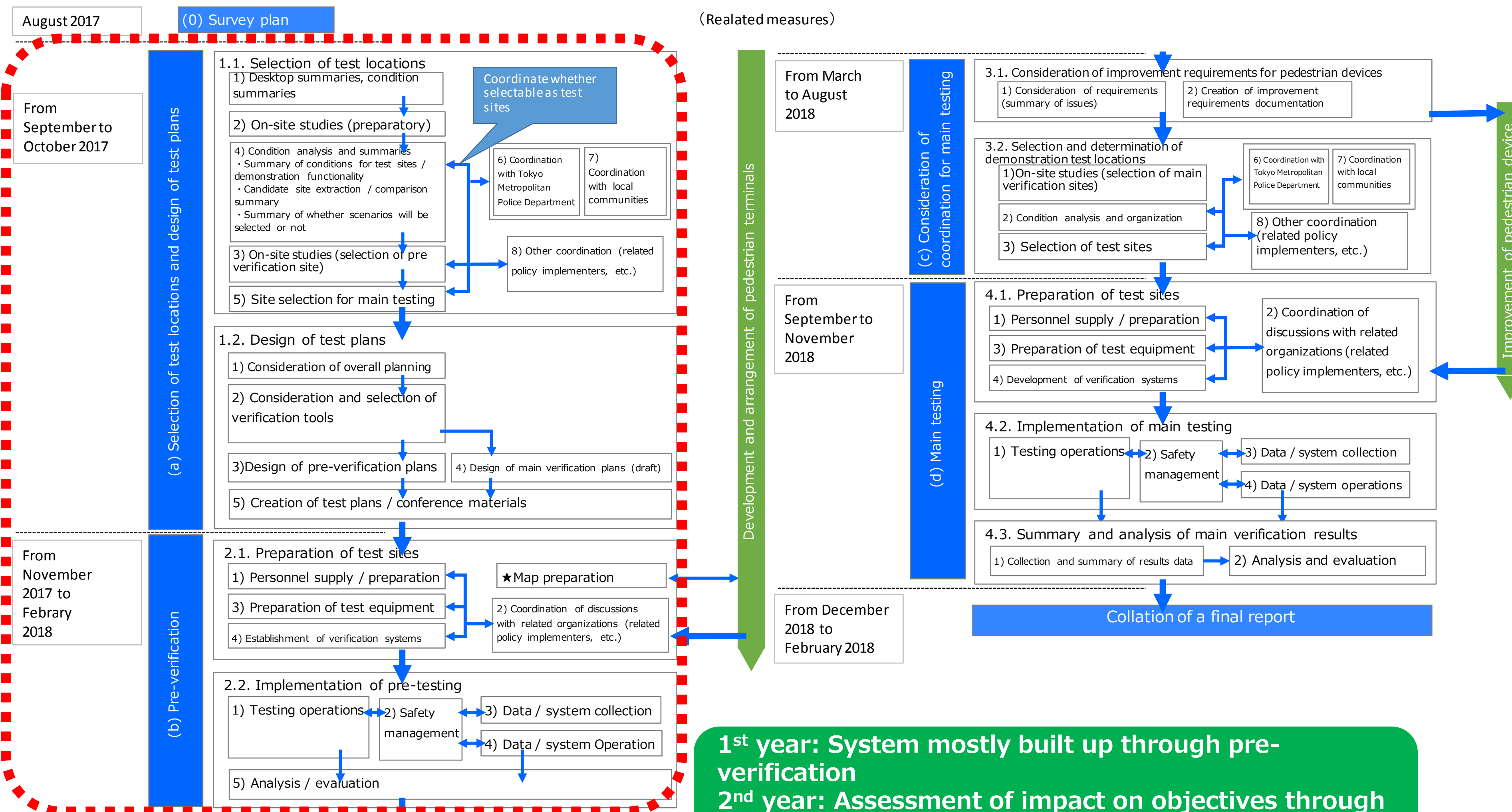
Demonstrating the effectiveness at pedestrian collision reduction of “providing alert information” in real traffic environments



2. Research progress report

- R&D flow

FY 2017 FY 2018



1st year: System mostly built up through pre-verification
2nd year: Assessment of impact on objectives through test-user demonstrations and consideration of methods of working toward implementation

■ Pre-test implementation results report (early report) summary

・FY 2017 objective (Ref. P1)	**To conduct functionality demonstrations in a variety of settings and determine aspects of improvement (equipment improvement, improvement in application for main verification) in preparation for the next fiscal year.**
・FY 2017 targets (Ref. P6)	**・After attaining the requisite number of samples, maintain proper operation rate at a minimum of 80% and the unnecessary operation rate at 20% or less in all chosen settings.** **・Summarize equipment habits and the differences between instances of proper and improper operations.**
・Conclusions (preliminary for early report) (Ref. P12 and subsequent)	**・Achieved correct operation rate at a minimum of 80% and incorrect operation rate at 20% or less in all settings.** **Summary of major points:** **・In terms of functionality, the following issues were identified:** **1) Improvements to notification mechanisms for "information provision" and "alert" when making left and right turns** **2) Improvements to notification thresholds during low-speed operation** **3) Improvements to altitude diagnosis precision** **・In terms of operations, the following issues were identified:** **1) Free-flow testing is extremely difficult** **(Vehicles and pedestrians do not encounter one another except via shotgun method)** **2) Difficulty with verification at high speeds due to safety management concerns**

(1) Selection of test locations and test scenarios

Test scenarios

- In pretesting, verify proper operation in scenarios requiring and not requiring assistance.
- In main testing, demonstrate the technology's effectiveness on lowering pedestrian accidents when implemented in real traffic environments.

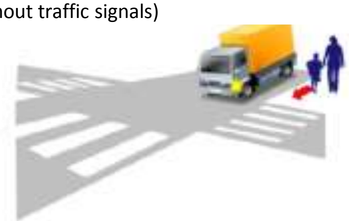
(i) Scenarios requiring support **(5 scenarios)**

(1) Pedestrian crossing of uninterrupted road sections

(2) Crossing of intersections with poor visibility

(3) Right turns at intersections (both with and without traffic signals)

(4) Left turns at intersections (both with and without traffic signals)



(5) Roads without sidewalks

Real, practical scenarios in which benefits are anticipated

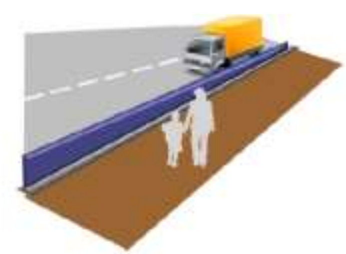
(ii) Scenarios not requiring support **(5 scenarios)**

(1) Inside vehicles

(2) Inside buildings

(3) On pedestrian footbridges

(4) Sidewalks



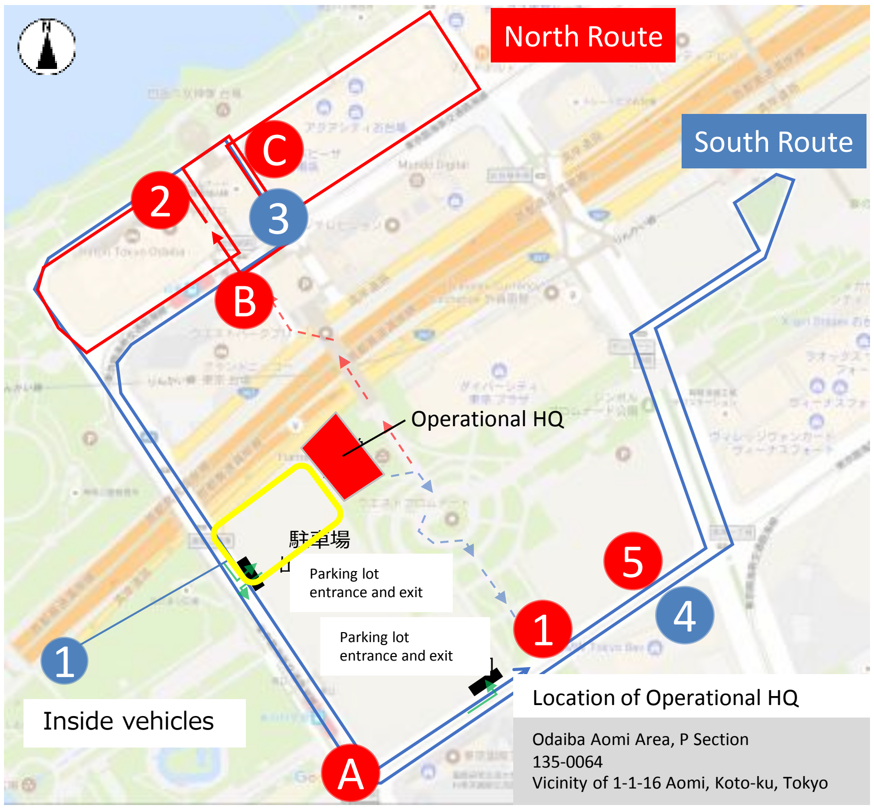
(4) Above and below elevated structures

Scenarios in which difficulty would be caused by assistive functions (as evaluated in pre-verification)

(2) Pre-verification

Verification period / locations / method

- **Feb. 13-15, 2018 (3 days + 1 day of preliminary verification [Feb. 12])**
- **Conducted in the Odaiba and Ariake areas**



2 verification scenarios for "scenarios not requiring support"

5 verification sites for "scenarios not requiring support"

1 Pedestrian crossing of uninterrupted road sections

2 Crossing of intersections with poor visibility

A Substitution proposal: Left/Right turn at intersections (w/ signal)

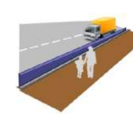
B Left/Right turn at intersecions (w/ signal)

C Left/Right turn at intersections (no signal)

5 Road without sidewalks

3 On a pedestrian footbridges

4 Sidewalks



(2) Pre-verification

Targets

- **Maintain correct operation rate at a minimum of 80% and incorrect operation rate at 20% or less in all chosen settings.**
- **Summarize equipment quirks and the differences between instances of correct and incorrect operations**

*Attain a certain number of samples so that proper verification of operation rates can be conducted **(target of 100 samples per scenario)**

・Tradeoff of proper operation rate and unneeded operation rate
・Consider device configurations that yield the lowest incorrect operation rate
・Derive numerical balance of correct operation rate and incorrect operation rate to which testers are most receptive

In pre-verification, attain statistical significance through generation of samples by repetition (aiming for 10% significance)
・Evaluation of proper system functioning and confirmation of status during improper functioning
・Factor analysis (discover abnormalities and problems, and reduce the risk of malfunction as much as possible during main demonstration)

Method of attaining sample quantity

Pedestrian walking conditions

1) Pedestrian locations
・Center
・Right-leaning
・Left-leaning

2) Crossing direction
(If walking across a pedestrian crossing)
・Straight forward

Vehicle driving conditions (speed)

1) Driving speed
・30 km/hr or less (assuming residential roads)
・40-60 km/hr (assuming highways / arterial roads)

2) Driving locations
・Center
・Right-leaning
・Left-leaning

Personnel conditions (Pedestrians)

・Children (walking at a standard speed)
・Adults (walking at a fast spped)
+Adults (walking at a slow speed)
・Elderly (walking at a slow speed)

Personnel conditions (Vecicles)

・Adults who drive on a daily basis
・Elderly adults who drive on a daily basis

Pedestrian walking conditions **3 patterns** ※Selected based on the scenario × Vehicle driving conditions (speed) **6 patterns** ※Selected based on the scenario × Personnel conditions **1 patterns** ※Selected based on the scenario

- **Set the number of patterns anticipated for each scenario and collect a sample quantity by which performance can be evaluated.**

For pre-verification, conduct a survey of testers via shotgun method (test-user survey)

Shotgun method
⇒ Method of judging when vehicles will encounter pedestrians and having pedestrians walk at appropriate timings

➢ However, also consider verification using "free" walking in preparation for main verification

(2) Pre-verification

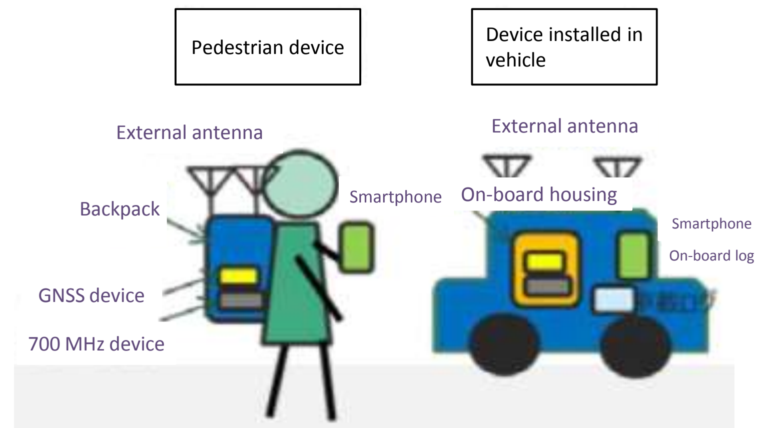
Testers / Equipment used

【Pedestrians: 18 ppl. / day; Pedestrian devices: 20 sets】

Smartphones with a “hazard detection app”

・Monitors the location data of its own device and another device (on-board device, etc.), calculates predicted collision points, and issues stages of alerts based on danger level.

・Testing performed with the devices in backpacks.



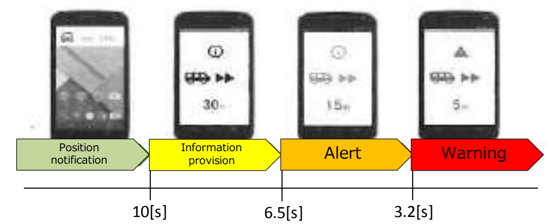
【Drivers: 5 ppl. / day; On-board device: 5 sets】

Smartphones with a “hazard detection app”

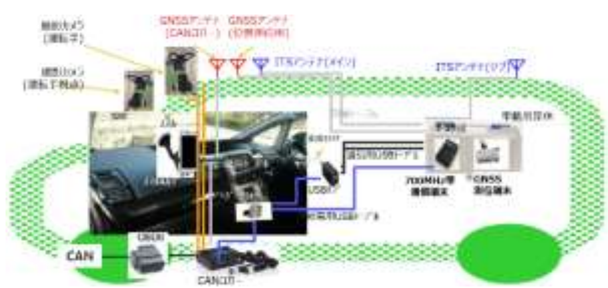
・Install ITS antennas, GNSS antennas, etc.

・Power supply via the cigarette lighter socket.

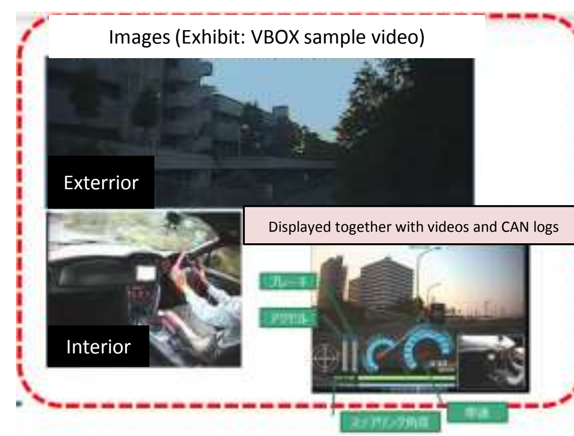
・Video taken together with CAN data to monitor vehicle behavior.



【Staff: 38 ppl. 】



Due to the specifications of the on-board equipment, the vehicles used are 3rd-generation Prius (XW30) 2010-2015.



(2) Pre-verification

Photos







(2) Pre-verification

Verification systems / equipment

During testing: Also used for safety monitoring of test-users

【Log analysis tools】

Smartphone (pedestrian / on-board)

Log acquisition on micro SD cards (approx. 130 MB / hour)

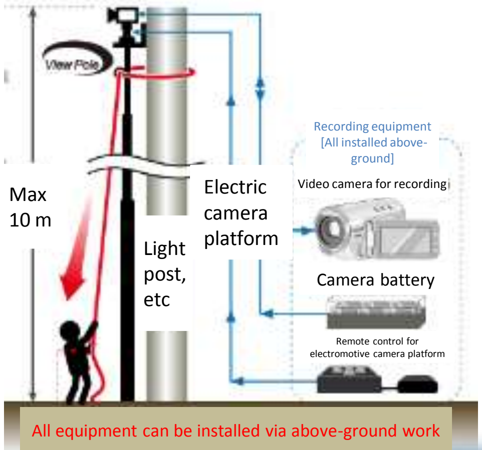
Log analysis tool

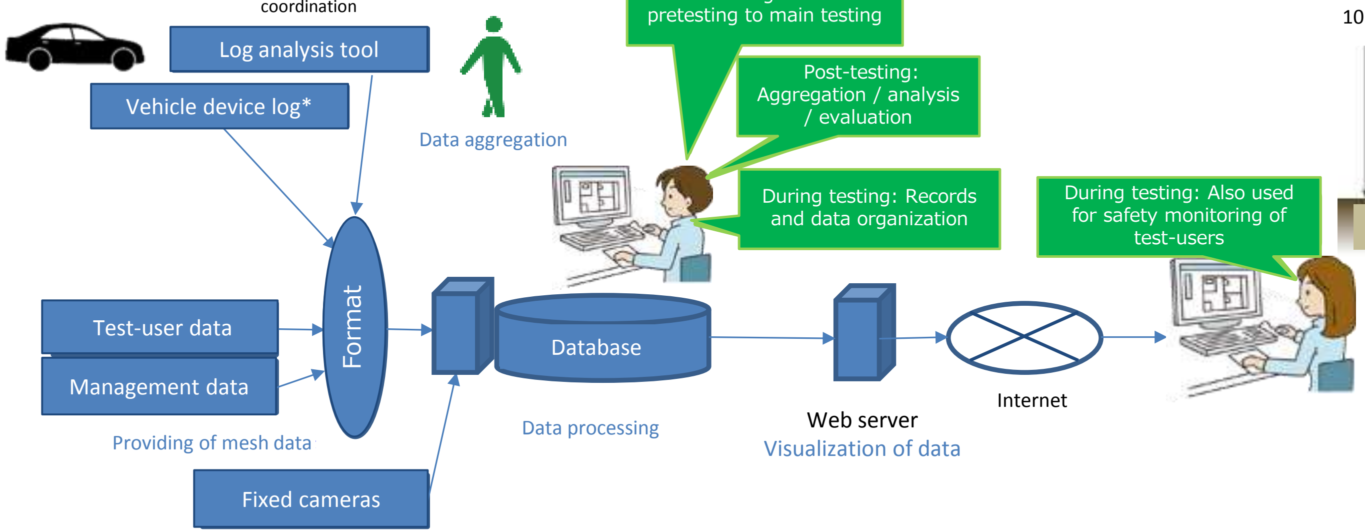
Ensures data consistency based on accurate time data acquired from bidirectional GNSS receptors, and then displays this data. This is planned to be further developed in the future.

CAN logger (on-board)

Log acquisition on SD cards (approx. 3 GB / hour)... incl. Data specifications and transmission specifications require confirmation and coordination

【Fixed cameras】



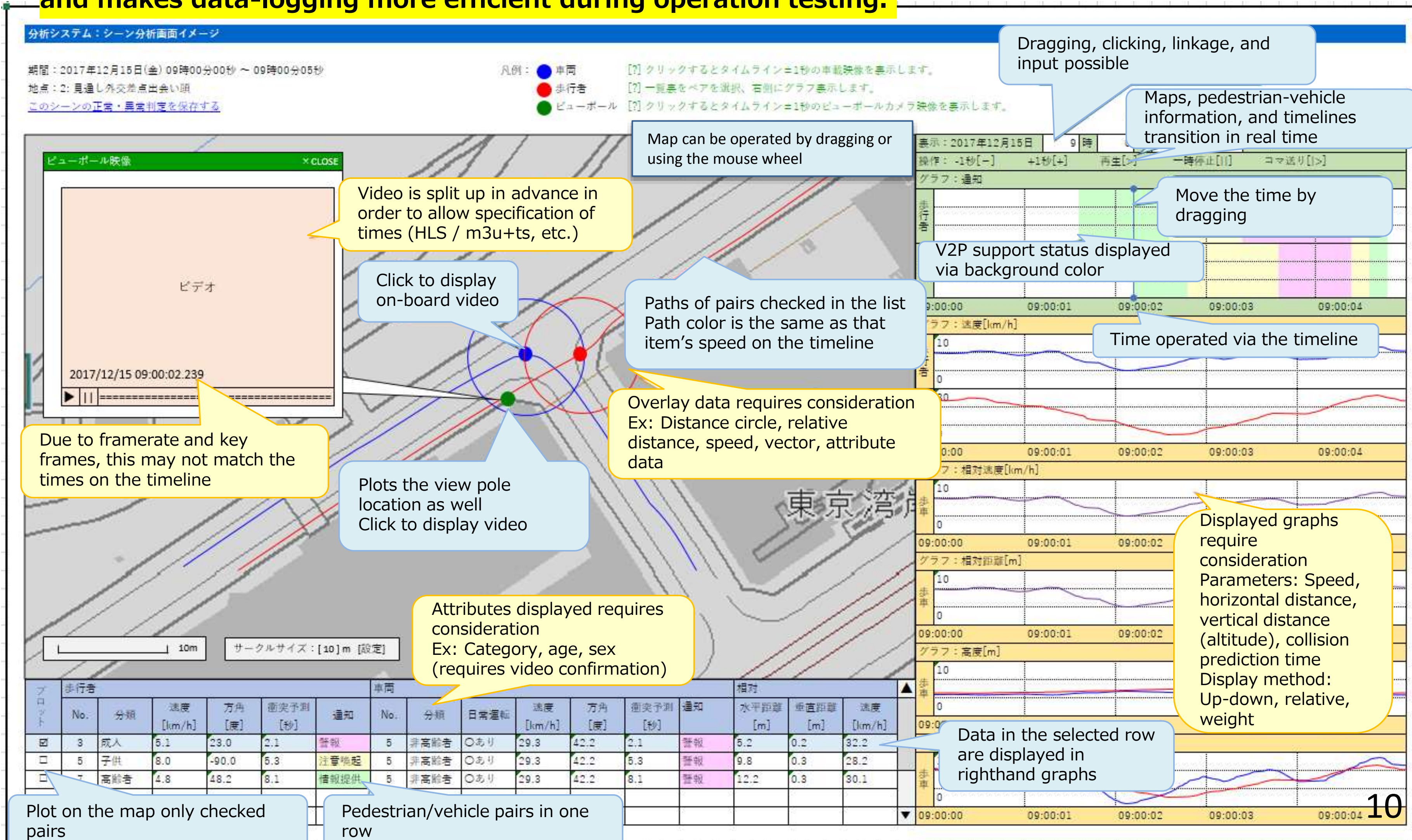


*Study also conducted via partially standalone cameras.

(2) Pre-verification

Log analysis tools

・Build a system that visualizes collected data, makes determinations of success/failure for efficient, and makes data-logging more efficient during operation testing.



(2) Pre-verification

Verification scenarios (excerpts)

・Conduct after planning out elements to be verified (other scenarios have been omitted)

Pre-verification route (2 – Crossing of intersections with poor visibility)

Vehicle traffic lines
Pedestrian traffic lines

Vehicle traffic lines
Pedestrian traffic lines
Anticipated verification patterns
Largest number of samples that can be collected via one verification session
Maximum 10 samples
[Conditions subject to verification]

・Direction	1 direction
・Speed	2 patterns
	*40-60 km/h speeds depend on traffic conditions on that day

(1) When turning at the signal in front of Daiba Station, Vehicle Management D issues a warning to Scenario Management D

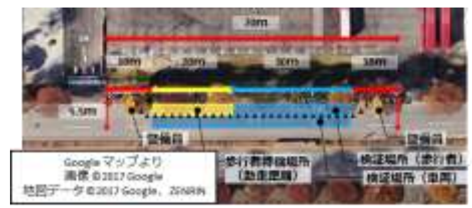
(2) Vehicle Management D issues a warning just before passing under a pedestrian bridge

(3) Scenario Management D received Vehicle D's warning and issues directions to pedestrians

(4) Pedestrian staff receive the directions from Scenario Management D and begin walking. After finished walking, results are input in the checklist.

Pre-verification route (5 – Roads without sidewalks)

D Pedestrian director
D Vehicle director



(1) While Verification Scenario 1 is undergoing verification, pedestrian staff will be made to stand by

(2) Vehicle Management D directs the driver to drive the vehicle in the center

(3) As the vehicle approaches the verification point, the guard guides the verification vehicle along the vehicle in the center

(4) As the guard is directing, pedestrian staff begin walking

(5) After the walking is complete, the result is input in the checklist.

(3) Pre-verification results

Number of samples acquired

"Scenarios requiring support"

01-1 : Pedestrian crossing of uninterrupted road sections	247 samples
02-1 : Crossing of intersections with poor visibility	180 samples
03-1 : Right turn at intersections (w/ signal)	178 samples
03-2 : Right turn at intersections (w/ signal) – possible substitute	228 samples
03-3 : Right turn at intersections (no signal)	177 samples
04-1 : Left turn at intersections (w/ signal)	177 samples
04-2 : Left turn at intersections (w/ signal) – possible substitute	250 samples
04-3 : Left turn at intersections (no signal)	185 samples
05-1 : Roads without sidewalks	257 samples

Total: 1,879 samples

W/ signal: Daiba Intersection

W/ signal (possible substitute): Museum of Maritime Science intersection

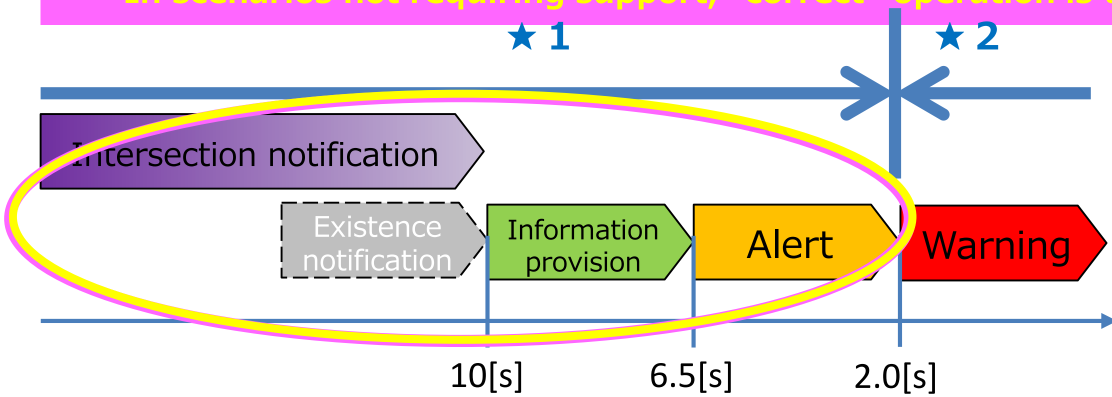
"Scenarios not requiring support"

06-1 : Inside vehicles	143 samples
07-1 : Inside buildings	118 samples
08-1 : On pedestrian footbridges	183 samples
09-1 : Sidewalks	101 samples
10-1 : Above and below elevated structures	182 samples

Total: 727 samples

(3) Pre-verification results: Correct operation rate, Incorrect operation rate

1) "Correct" operation is that in which intersection notification, information provision, or alert notification is properly issued.
In scenarios not requiring support, "correct" operation is that in which no notification is issued.

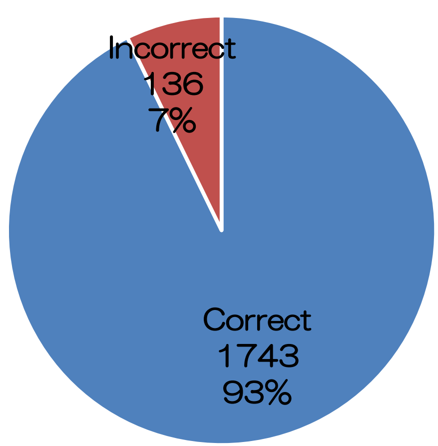


★ 1 : Information notification range in which the system is expected to function

★ 2 : Range in which vehicle performance and hardware (and not this system) should ensure safety (possibility that notifications will not arrive in time)

***"Existence notification"** are not issued as they may be troublesome for users.

Scenarios requiring support



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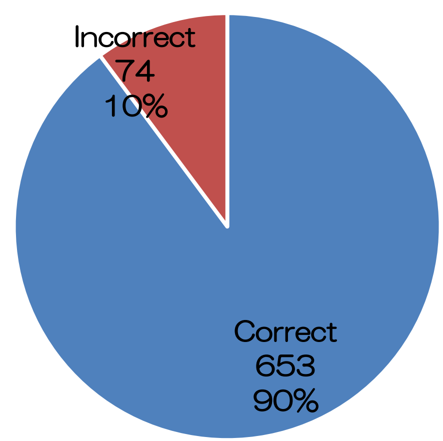
Scenarios not requiring support



n=727

(3) Pre-verification results: Correct operation rate, Incorrect operation rate

Judgements of correct / abnormal functioning for each scenario

"Scenarios requiring support"

[Scenarios]	[# of samples]	[Correct]	【Incorrect (alarm only) 】	【Supported (correct detection)】
01-1 : Pedestrian crossing of uninterrupted road sections	247	231	16 (12)	**94%**
02-1 : Crossing of intersections with poor visibility	180	156	24 (15)	**87%**
03-1 : Right turn at intersections (w/ signal)	178	162	16 (13)	**91%**
03-2 : Right turn at intersections (w/ signal) – possible substitute	228	208	20 (1)	**91%**
03-3 : Right turn at intersections (no signal)	177	164	13 (7)	**93%**
04-1 : Left turn at intersections (w/ signal)	177	166	11 (7)	**94%**
04-2 : Left turn at intersections (w/ signal) – possible substitute	250	236	14 (0)	**94%**
04-3 : Left turn at intersections (no signal)	185	178	7 (2)	**96%**
05-1 : Roads without sidewalks	257	240	17 (2)	**93%**

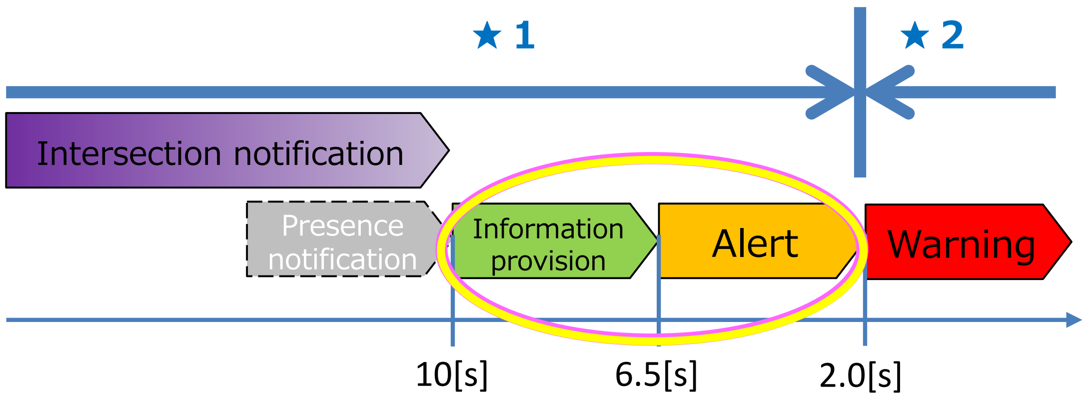
"Scenarios not requiring support"

[Scenarios]	[# of samples]	[Correct]	【Incorrect (alarm only) 】	【No notification (correct detection)】
06-1 : Inside vehicles	143	132	11	**92%**
07-1 : Inside buildings	118	118	0	**100%**
08-1 : On pedestrian footbridges	183	152	31	**83%**
09-1 : Sidewalks	101	94	7	**93%**
10-1 : Above and below elevated structures	182	157	25	**86%**

Successfully maintained proper detection of scenarios requiring support at 80% or above, and abnormal operation in scenarios not requiring support at 20% or below.

(3) Pre-verification results: Issues in functionality (1)

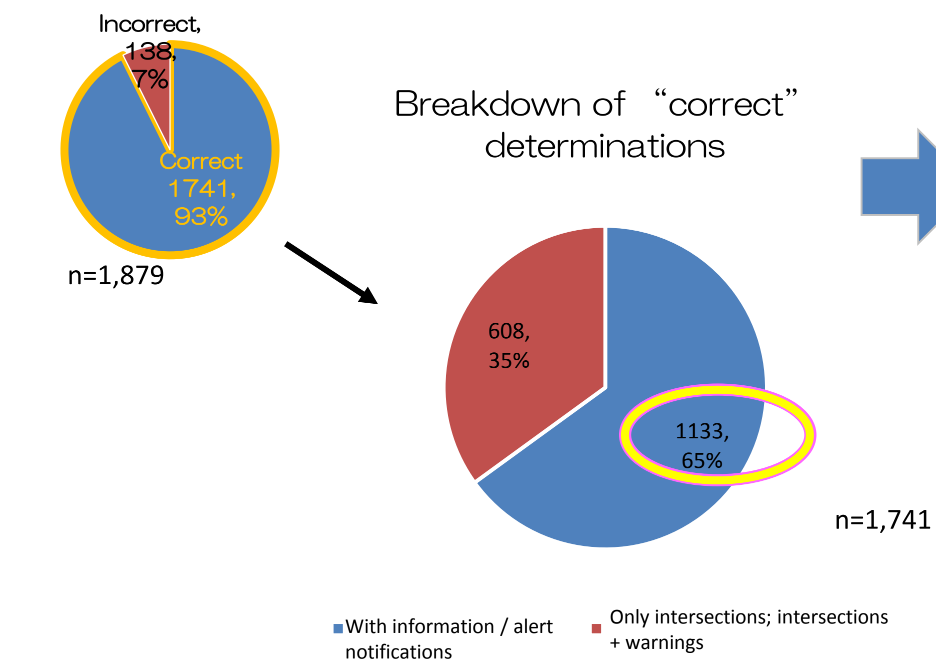
1) Improvements to notification mechanisms for “information provision” and “alert” when making left and right turns



★1: Information notification range in which the system is expected to function

★2: Range in which vehicle performance and hardware (and not this system) should ensure safety (possibility that notifications will not arrive in time)

Scenarios requiring support



No information provision or alert notifications were issued in approx. 40% of samples in which “correct” determinations were made.

Jugdement notifications reliably issued for intersections, but information provision and alert notifications were found to not have been issued in particular in left/right turns.

(3) Pre-verification results: Issues in functionality (1)

Among “correct” judgements in scenarios requiring assistance, this section checks cases in which only intersection notifications were issued.

“Scenarios requiring assistance”

[Scenarios]	[# of samples]	[Correct]	[With information provision / alert]	【Only intersection notification / intersection + warning】
01-1 : Pedestrian crossing of uninterrupted road sections	247	231	231	0
02-1 : Crossing of intersections with poor visibility	180	156	136	20
03-1 : Right turn at intersections (w/ signal)	178	162	100	**62**
03-2 : Right turn at intersections (w/ signal) – possible substitute	228	208	87	**121**
03-3 : Right turn at intersections (no signal)	177	164	73	**91**
04-1 : Left turn at intersections (w/ signal)	177	166	87	**79**
04-2 : Left turn at intersections (w/ signal) – possible substitute	250	236	99	**137**
04-3 : Left turn at intersections (no signal)	185	178	80	**98**
05-1 : Roads without sidewalks	257	240	240	0

- In the mid-intersection scenarios (03-1 to 04-3), there were many cases in which only an intersection notification was issued, without information provision or alert notifications.

➡ For left/right turn determinations, it is planned to conduct detailed analysis of 1) the range set for intersection notifications, 2) conditions for distances from pedestrians, etc., and conduct appropriate tuning (revision of intersection ranges, etc.)

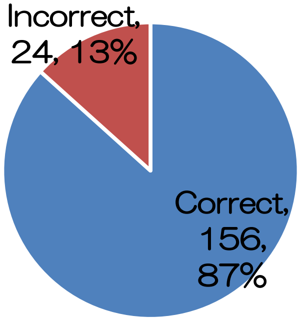
(3) Pre-verification results: Issues in functionality (2)

2) Improvements to notification thresholds during low-speed operation

Scenario requiring support: 2) Crossing of intersections with poor visibility

- **Vehicle accelerates to approx. 30 km/hr, then decelerates (incl. temporary stops)**
- **Judgements were generally correct with correct notifications.**
- **Five samples in which both pedestrians and vehicles suddenly received "alarm" notifications**
  ⇒ Possibility that vehicle acceleration changes and pedestrian start locations had an effect

O2-1: Crossing of intersections with poor visibility



n=180

➡ Plan to conduct detailed analysis of the factors, etc., underlying notifications not based on the "Information Provision → Alert → Warning" process.

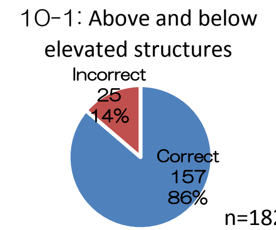
(3) Pre-verification results: Issues in functionality (3)

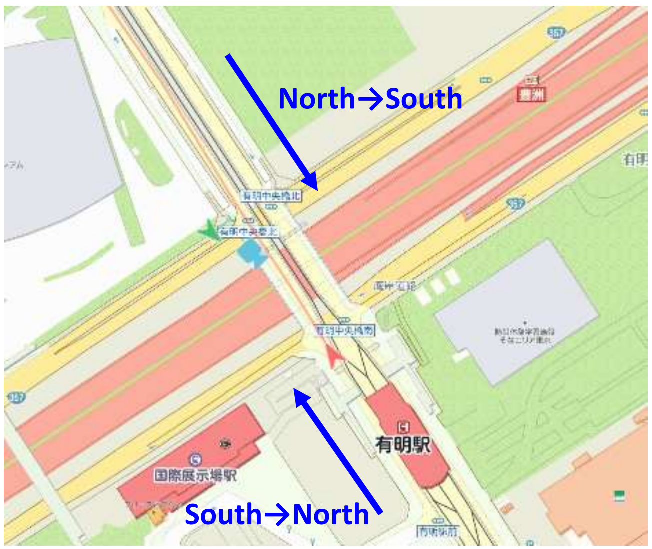
3) Improvements to altitude diagnosis precision

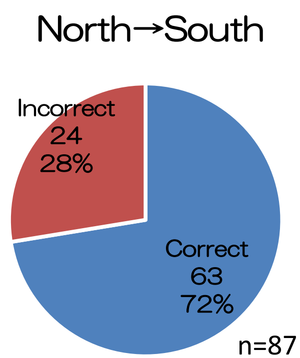
Scenario requiring support: 5) Above and below elevated structures

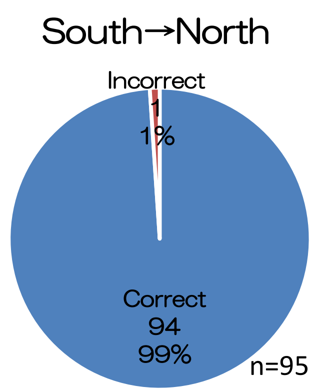
- ▶ **Vehicles travel from north to south on Ariake Central Bridge (vehicles begin in front of the ascent)**
- ▶**In some cases, notifications were only given to pedestrians underneath elevated structures**

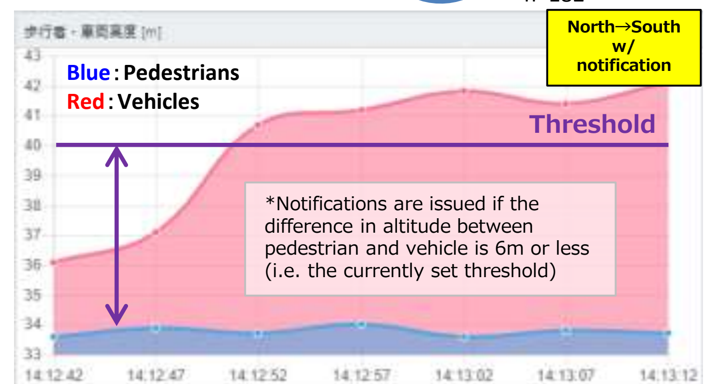
⇒ **Analysis by pattern based on the direction in which vehicles are driving**

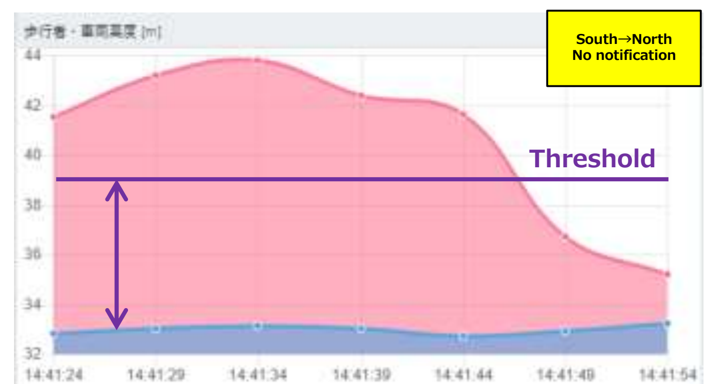












➡ Possibility that a notification will be issued if the vehicle's collision prediction radius overlaps with pedestrians before the air pressure sensor values rise.
➡ Relies on the sensitivity of air-pressure sensors.

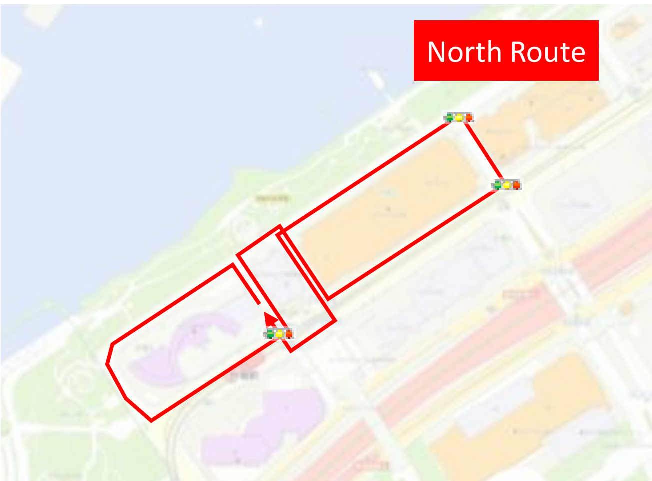
(3) Pre-verification results: Issues in operation (1)

1) Free-flow testing is extremely difficult

▶ On the final day of testing (2/15), the route was divided into the north and south routes, and testing was conducted in a free-flow manner.
▶ In free-flow testing, the north route was split among 20 pedestrians and 3 vehicles.
▶ In free-flow testing, the south route was split among 20 pedestrians and 5 vehicles.

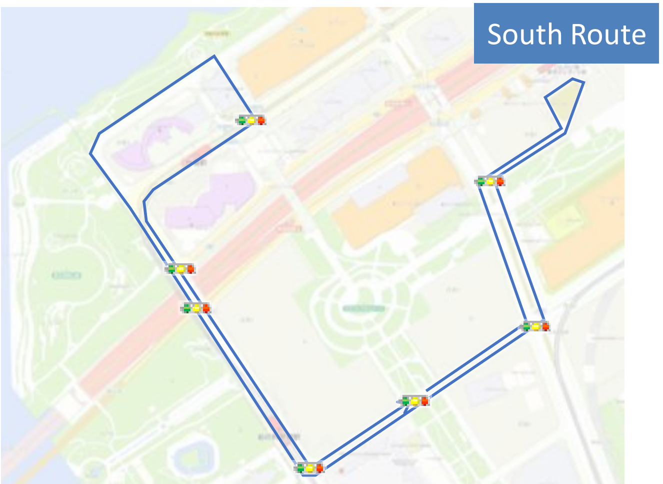
【North route】

・Numerous signals, heavy traffic, etc. caused overlap among test vehicles and problems with detection.
・Pedestrians were made to walk separately, but in many cases they overlapped with one another intersections.



【South route】

・Long total length with few opportunities for pedestrians and vehicles to come in contact.
・Pedestrians attempted to line up their timings with vehicles, but numerous roadside trees and cars parked on streets resulted in poor visibility, making it hard to choose the right timings.

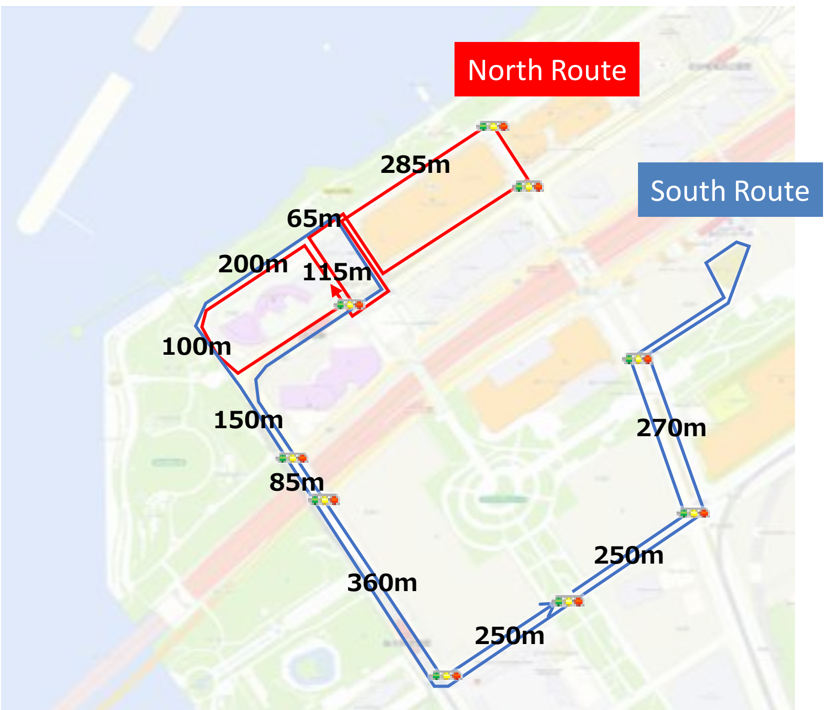


➡ There will be no major improvements achieved by increasing the number of vehicles. In order to improve encounter rates, there is a need to increase the number of pedestrians. There is also a need to verify ideal environments in which free-flow driving is possible, such as routes with little traffic or shorter route lengths.

(3) Pre-verification results: Issues in operation (2)

2) Difficulty with testing at high speeds due to safety management concerns

- ▶ **In pre-verification, verification was limited to around 30 km/hr at most.**
- ▶ **It is difficult to verify pedestrian collision risk at high speeds.**
- ▶ **The Odaiba test field in particular is unsuitable for high-speed verification with its many traffic signals, high traffic, and short road sections.**



【Test at 60 km/hr】

・A vehicles requires approx. 50m to rapidly accelerate from a stopped state to 60 km/hr.
・A vehicle moving 60 km/hr requires approx. 40m to stop.

Necessary minimum of 100m required

Table: Braking distances

Speed	Stopping distance	Idle running distance	Breaking distance
20km	**8m**	6m	2m
40km	**20m**	11m	9m
60km	**37m**	17m	20m
80km	**58m**	22m	36m
100km	**84m**	28m	56m
120km	**114m**	33m	81m

➡Verification at high speeds on these routes entails high risks during main verification. High-speed verification should be conducted not on public roads but at test sites.

(3) Pre-verification results: Test-user opinions, etc.

Evaluation from staff & system checks

- Logging data using check sheets
  - Monitor how pedestrians and drivers feel (notification timings, etc.)
    - Many intersection notifications
    - Notification timings feel slow overall (esp. warnings)

  - Monitor roadside parking and other road conditions
    - Warning timings change based on roadside parking, amount of traffic, whether a bus is travelling in front, etc.

  - Supplemental analysis by the systems
    - Unclear record methodology for notifications outside of verification (pre-warning)

Evaluation from tools

- Log analysis using systems
  - Reproduce testing scenarios
    - Visualization of notification timings

  - Detailed analysis of relationships between notifications and pedestrian speed changes, etc.
    - Monitor pedestrian speed changes when notifications are received (slowing down due to looking over one's shoulder, etc.)

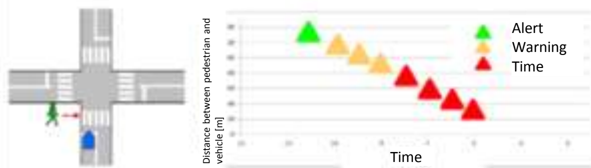
(3) Pre-verification results: Verification (future)

Verification (future)

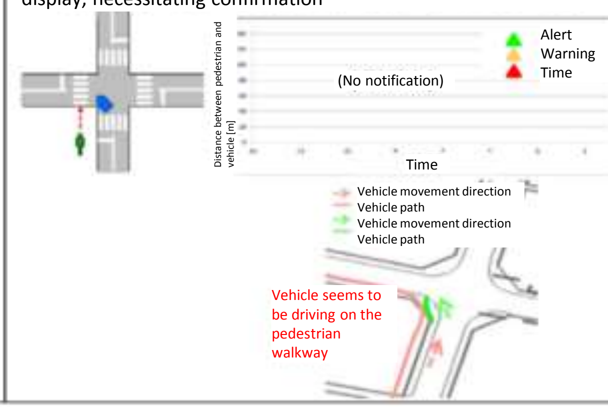
Verification of hazard notifications in “scenarios requiring assistance”

Compare notification status with maps and graphs to verify the hazard notification

Example of correct operation in a “scenario requiring support”
⇒ Notification in hazardous conditions



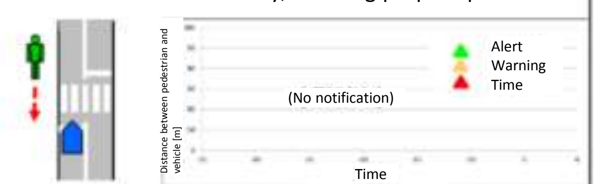
Example of improper operation in a “scenario requiring support”
⇒ No notification issues even in hazardous conditions
⇒ Uncertain variation (error) in location measurement in map display, necessitating confirmation



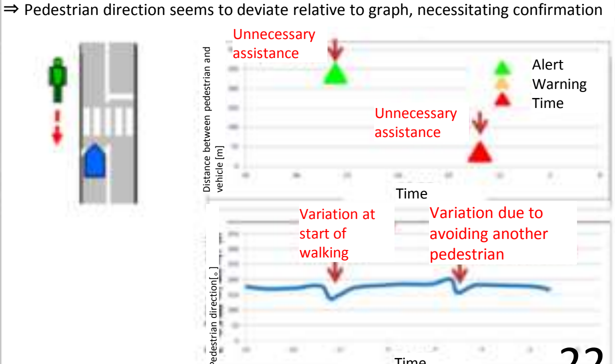
Verification of hazard notifications in “scenarios not requiring assistance”

Compare notification status with maps and graphs to verify the hazard notification

= Example of proper operation in a “scenario not requiring support”
⇒ No notification on walkway, meaning proper operation



Example of improper operation in a “scenario not requiring support”
⇒ On walkway but unneeded assistance is provided, meaning that it is inccorect operation
⇒ Pedestrian direction seems to deviate relative to graph, necessitating confirmation



(4) Coordination and considerations in preparation for main verification

Consideration of device improvement requirements

Organize improvement requirements for pedestrian devices based on the results and issues determined through pre-verification, and conduct discussions with businesses responsible for equipment development.
Improvement policies (determined by the contractor undertaking the relevant measures)

Summarize improvement requirements and send to device improvement team

Selection and determination of locations for implementation of main demonstration tests

Reconsider implementation locations for main testing based on the results of pre-verification. Primarily focusing on cases in which assistance is required, conduct a careful study of test sites and consider whether a location is appropriate for accident-reduction initiatives and whether the areas are appropriate in extent for pedestrian testers to walk around. Also re-set conditions for the traffic situation, weather, etc.

Extract sufficient anticipated use patterns (environmental conditions)
Study and respond

Preparation of locations for conducting main demonstration tests

Prepare personnel, equipment, and verification systems for main testing. Where necessary, conduct discussions and coordinate with road administrators, local relevant parties, etc.

Prepare plans by which testing can be conducted with due consideration for safety

	Daily driving	No Daily driving
Not elderly	A	~~B~~
Elderly	C	~~D~~

Child	A
Adult (excl. elderly)	B
Elderly	C

(5) Main verification

Implementation plan

■Period: Approx. 4-5 days

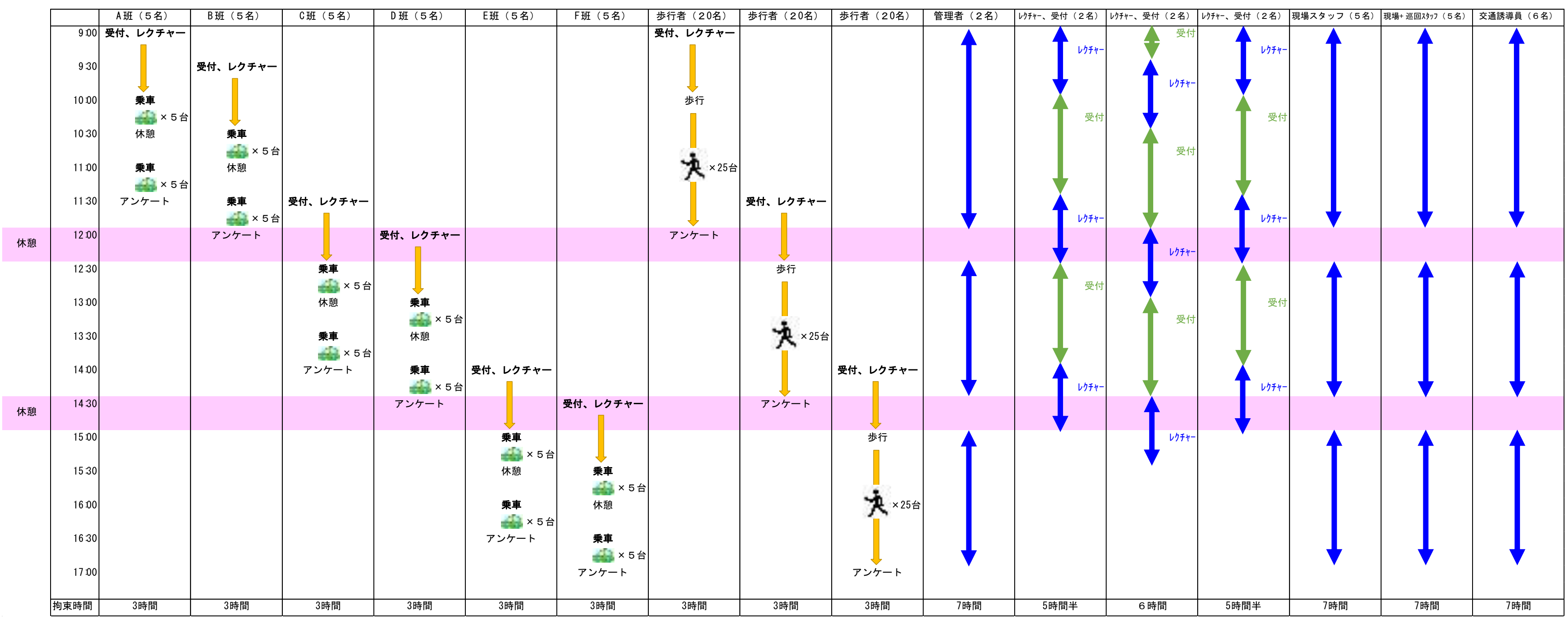
■Target: Pedestrians (elderly, adults, children) × Drivers (Elderly, adults)

Conduct evaluation primarily in scenarios where assistance is required.

【Flow of the test】

Flow of the test is assumed to be as follows.
Routes are indicated to vehicles and pedestrians, followed by movement.

【Test operation】
Consider shotgun methods and free-flow methods of testing, then conduct test-use operations in groups.



(5) Main verification

Implementation details

【Proposed verification items】

1) Visualize pedestrian / vehicle location information and confirm that information is provided correctly under dangerous circumstances
Extract dangerous situations from video data, calculate the percentage of such times that information was provided, and evaluate. Aim for a target of 80%-100%.
2) Compare behavior and awareness in dangerous situations in which pedestrians and vehicles are given information and those in which they are not given information
【Pedestrian behavior and awareness】 Compare pedestrian behavioral characteristics in situations in which a vehicle equipped with a device approaches versus situations in which a vehicle not equipped with a device approaches. Evaluate qualitatively based on video stills and questionnaires. Aim for a state of affairs in which the provision of information results in safer behavior and greater peace of mind.
【Vehicle behavior and awareness】 Compare vehicle behavioral characteristics in situations in which a vehicle encounters a pedestrian holding a device versus situations in which a vehicle encounters a situation not holding a device. Evaluate qualitatively based on video stills and questionnaires. Aim for a state of affairs in which the provision of information results in safer behavior and greater peace of mind.
3) Analyze pedestrian and vehicle behavior by scenario, and compare changes in behavior caused by information provision
Conduct scenario-by-scenario comparisons regarding (2) above, identifying scenarios in which information provision is effective. Aim for there to be benefits in as many scenarios as possible.

(5) Main verification

Implementation details

【Proposed verification items】

4) Conduct at times of day with heavy / moderate / light pedestrian and vehicle traffic to compare and analyze
Focus on times of day with many other pedestrians/vehicles and few other pedestrians/vehicles, comparing behavior and awareness. Use video and questionnaire results. Assume that benefits will be limited at times with may other pedestrians and vehicles. Aim to collect issues in need of future resolution through the propagation of equipment.
5) Conduct simple demonstrations in rainy weather to compare for analysis with conditions under sunny weather
Compare behavior and awareness in sunny and rainy weather. Use video and questionnaire results. Aim for the result that there are benefits in both.
6) Select testers such that there is variation in age and attributes, comparing differences in behavioral changes due to information provision
Analyze behavior and questionnaires to assess whether the elderly, children, etc. are feeling the benefits. Conduct cross-analysis on individual attributes regarding videos and questionnaires. Aim for larger benefits to be enjoyed by vulnerable road users such as the elderly and children.

3. Research targets

R&D targets and implementation-oriented initiatives

FY 2017 midterm targets : Conduct pre-verification. Achieve target proper operation rate and unnecessary operation rate. Create requirement documentation for device improvements.

FY 2018 final targets : Conduct main verification. Achieve target proper operation rate and unnecessary operation rate under real traffic conditions. Realize the benefits of “information provision” through video and questionnaire analysis.

Final result targets : Promote the social value of pedestrian location broadcasting technology, device development, and related services that aim to lower pedestrian-vehicle accidents, which account for half of traffic deaths.