Professional Design & Engineering Firm

FY2021～FY2022 Report

The Second Phase of Cross-Ministerial Strategic Innovation Promotion Program / Automated Driving for Universal Services / Technological Development and Establishment of Simulation Environment for Lane Merging Assistance

February 2023

KOZO KEIKAKU ENGINEERING Inc.

1. Outline of Research

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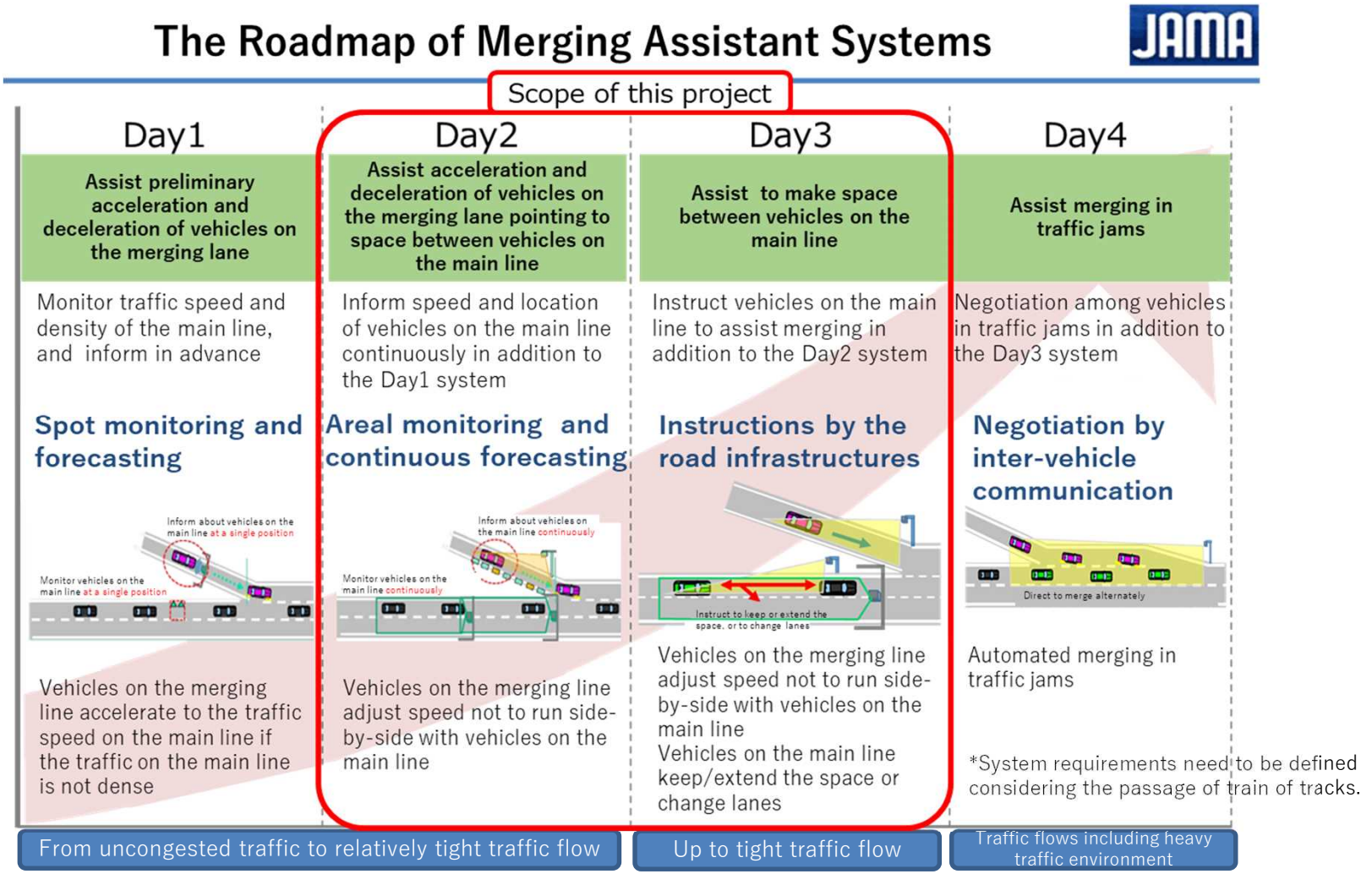
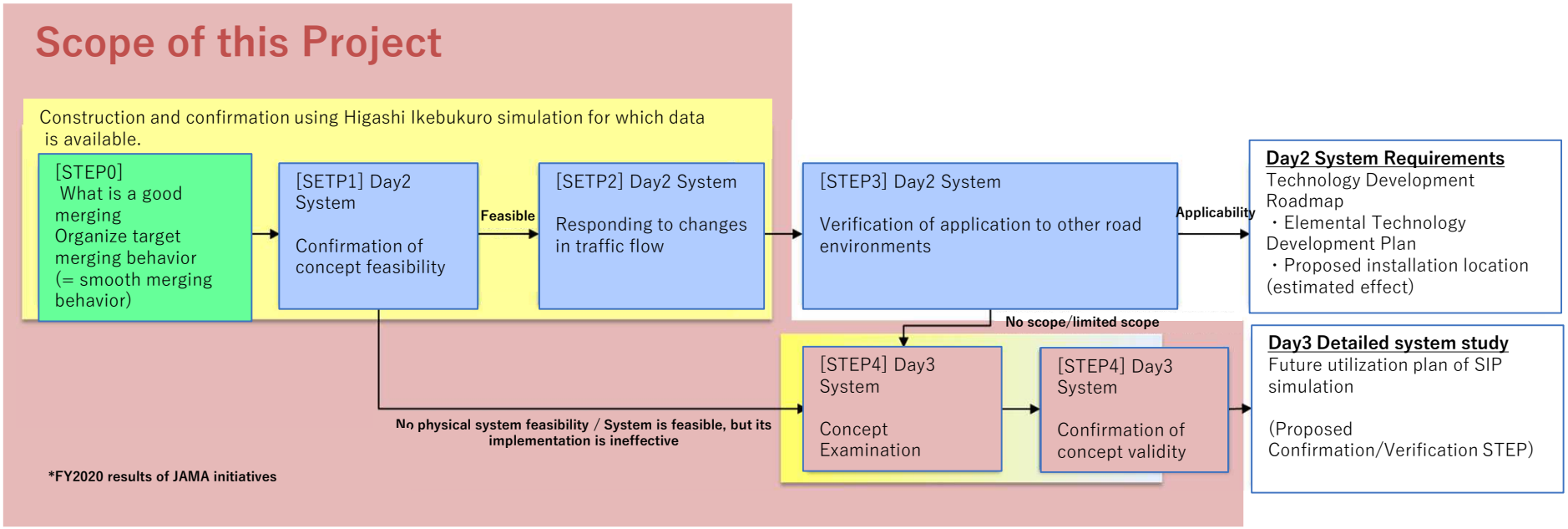
Roadmap of Merging Assistant

- Merging assistant systems aim to achieve smooth speed adjustment and merging on expressways and other roads by providing information to vehicles.
- Merging assistant systems are considered to evolve in the following four phases.



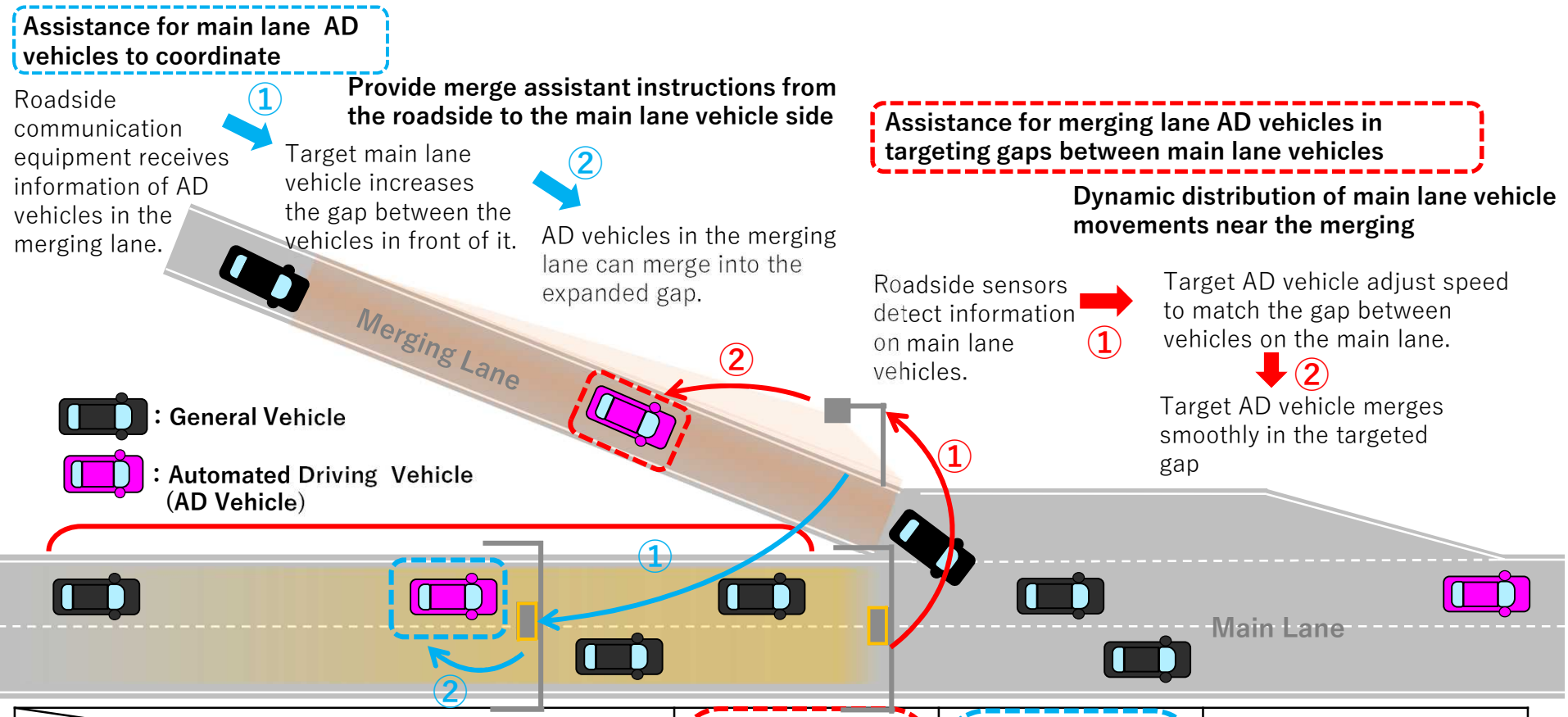
1. Outline of Research
Scope of the Project

- In this project, verification through simulation was conducted for the Day 2 and Day 3 systems.
- Verification of service effectiveness and issues for social implementation with the aim of early realization of the merging assistant service.



1. Outline of Research
Summary of Day2 System and Day3 System

- The Day 2 and Day 3 systems to be verified for this project are outlined below

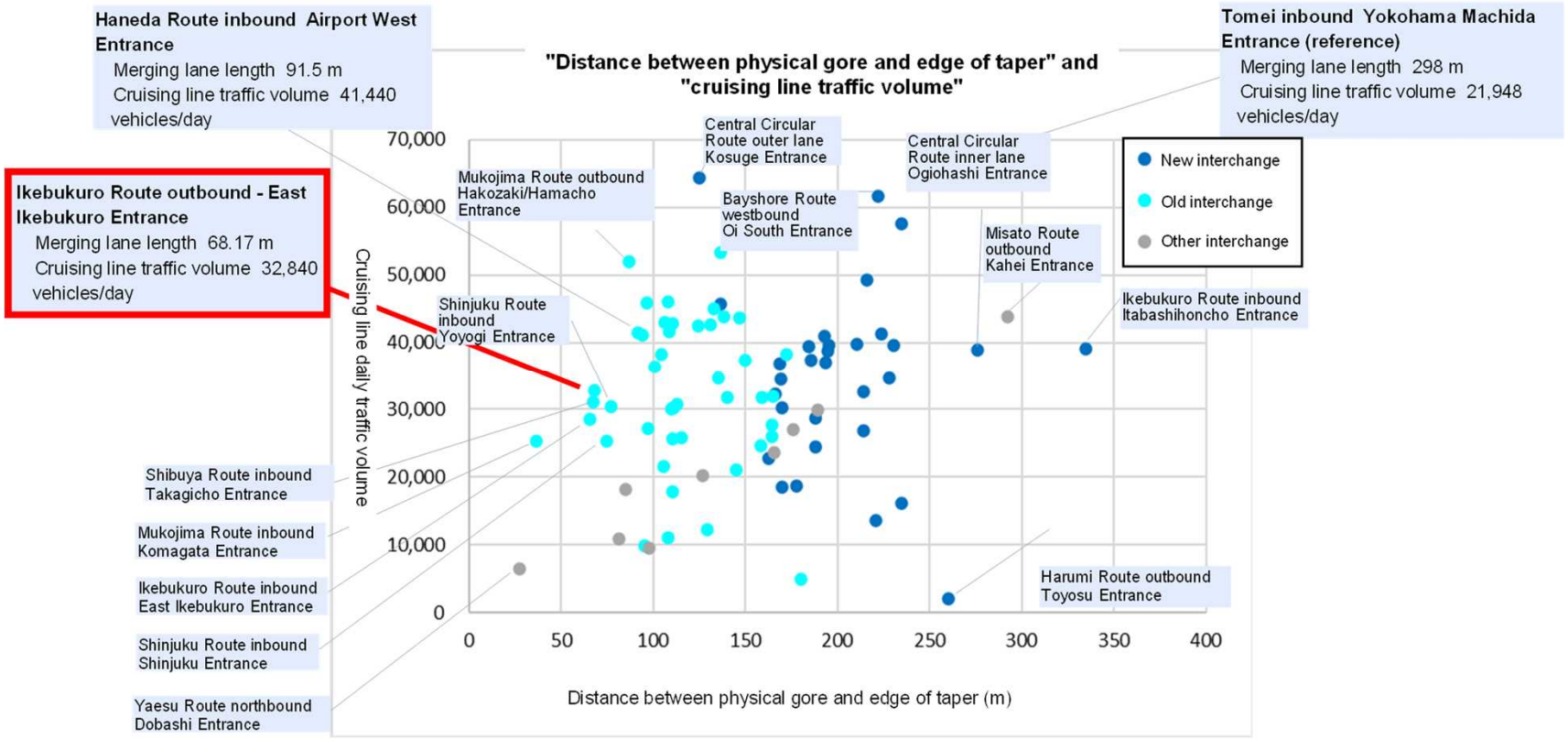


	Assistance to AD vehicles in merging lane	Assistance to AD vehicles in main lane	Final Scope of FY 2022
Day2 System **Assistance for merging lane AD vehicles in targeting gaps between main lane vehicles**	○	–	**To confirm changes in traffic flows due to install the system**
Day3 System **Assistance for main lane AD vehicles to coordinate**	○	○(depend on the situation)	**To confirm the feasibility of the concept**

1 . Outline of Research
Selection of Area for the Simulation

- Arrange the entrance merging lane lengths and main lane traffic of Metropolitan Expressway
  - The Higashi Ikebukuro Entrance on the off-ramp of Ikebukuro Line of the Metropolitan Expressway No.5 (hereinafter referred to as “Higashi Ikebukuro Entrance”) is an extremely short merging lane among the old standard (merging lane length standard is short) entrance and is an effective location for studying the installation of a merging assistant system.
- A simulation model that reproduces the merging behavior of vehicles at the Higashi Ikebukuro Entrance is available, based on the vehicle trajectory data created by the SAKURA Project of METI (Ministry of Economy, Trade and Industry).

➢ The Higashi Ikebukuro Entrance was selected as the target location for evaluation of this initiative.



* Analysis was performed for locations where distances could be measured based on aerial photographs.

2. Construction of Day2 and Day3 System Verification Environment

2. Construction of Day2 and Day3 System Verification Environment

- Three elements were implemented, but there are some points to keep in mind.

1. Definition of good or bad merging behavior
   - To evaluate the merging behavior using the Day2 and Day3 system, an index was defined to evaluate the merging behavior by scoring it as good or bad.

2. Construction of Simulation Environment
   - A simulation environment was built to study the merging assistant system, and the driving behavior of vehicles and roads in Higashi Ikebukuro were implemented.
   - The mechanism of the Day2 and Day3 systems were considered, and each assistant system was implemented in the simulation environment.

3. Analysis scenario
   - We studied scenarios to reproduce the traffic conditions in Higashi Ikebukuro by running the simulation environment.

– Points to keep in mind when conducting this analysis
   - Points to keep in mind when conducting the analysis by simulation were summarized.

2-1. Definition of good or bad merging behavior Construction of Merging Evaluation Score Map (1/2)

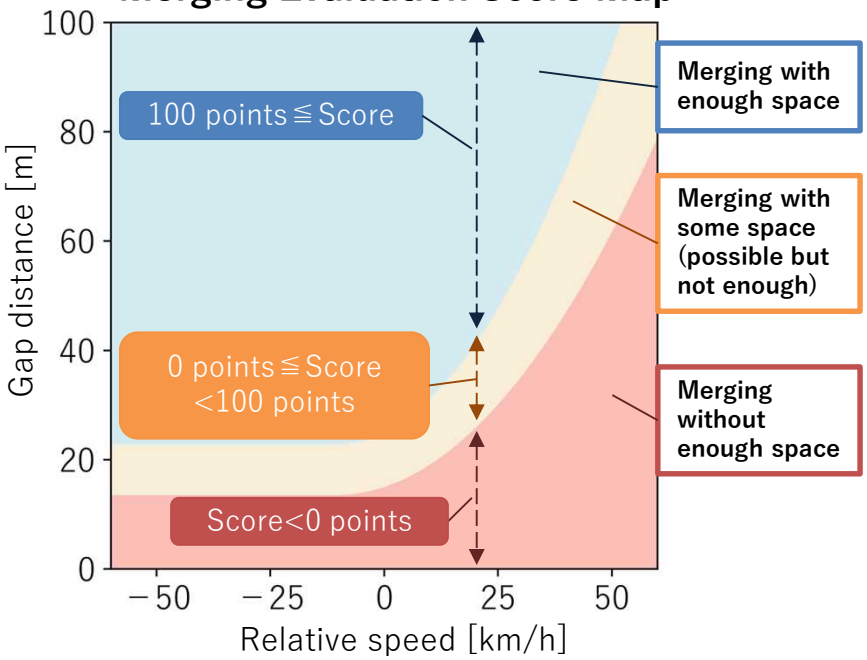
- Constructed an “Merging Evaluation Score Map" as a function that calculates a score (evaluation score) representing the level of leeway for merging based on the “gap distance" and "relative speed" between the merging vehicle and the surrounding vehicles on the main lane.
- Classify the degree of margin for merging according to the evaluation scores as a definition of whether the merge is good or bad.
- To analyze by using evaluation score, 2 point of views below are considered.

The point of view of improvement effect for merging by the assistant system.
-> to see that, check the range of improvement in evaluation scores.

The point of view of the conceptual feasibility* of the assistant system
-> to see that, check whether the merging is no longer evaluated as "Merging without enough space"

※ conceptual feasibility : is whether the improving effect of merging assistance is confirmed considering the blurring of probability distribution by using simulation.

Merging Evaluation Score Map

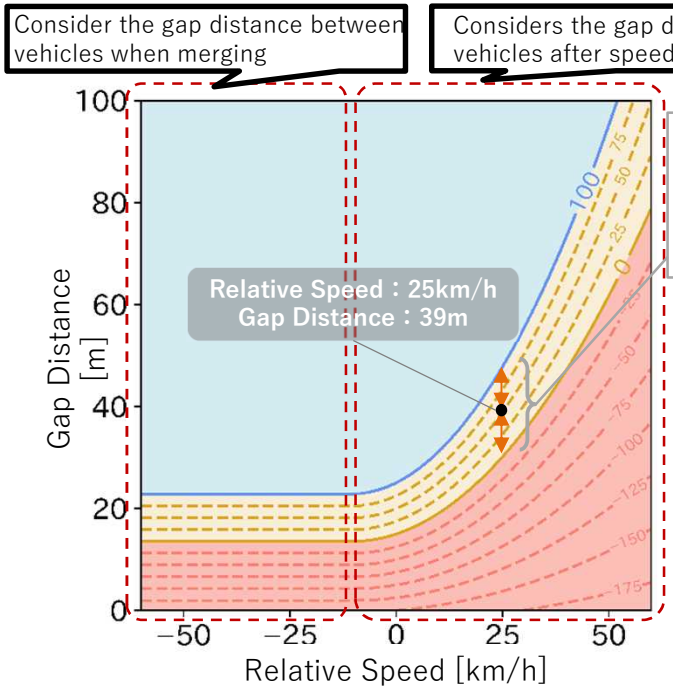


	Speed adjustment after merging	Gap distance between vehicles after speed adjustment
Score in blue zone : Merging with enough space	Weak deceleration of less than 0.2G* required	25m* or more enough space for merging
Score in yellow zone : Merging with some space(possible but not enough)	Deceleration of 0.2~0.3G* required	15~25m* adequate space for merging
Score in red zone : Merging without enough space	0.3G* or stronger deceleration is required	Less than 15m* not enough space for merging

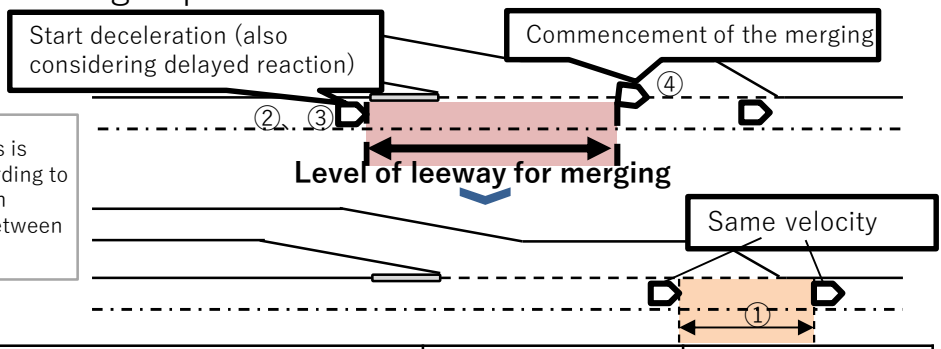
* **Sources are listed in ※ 1-4 on the next page.**

2-1. Definition of good or bad merging behavior Construction of Merging Evaluation Score Map (2/2)

- Concepts Included in the Merging Evaluation Score Map
  - When the main lane vehicle approaches to the merging vehicle, the deceleration required to adjust speed after merging and the gap distance between the vehicles after adjusting speed are considered to determine whether it is “Merging with enough space.”
  - If the main lane vehicle is moving away from the merging vehicle, no post-merge speed adjustment is required, so the gap distance between the vehicles at the time of merging is used to determine whether it is “Merging with enough space.”



The number of points is equally divided according to the distance between vehicles (distance between arrows).



	0 points	100 points
①Gap distance after the merging vehicle deceleration [m]	15※1	25※2
②Reaction delay time [s]	1.0※3	1.5※3
③Deceleration degree [G]	0.3※4	0.2※4
Level of leeway for merging (x:relative speed)	$\frac{x^2}{0.6G} + 1.0x + 15$	$\frac{x^2}{0.4G} + 1.5x + 25$

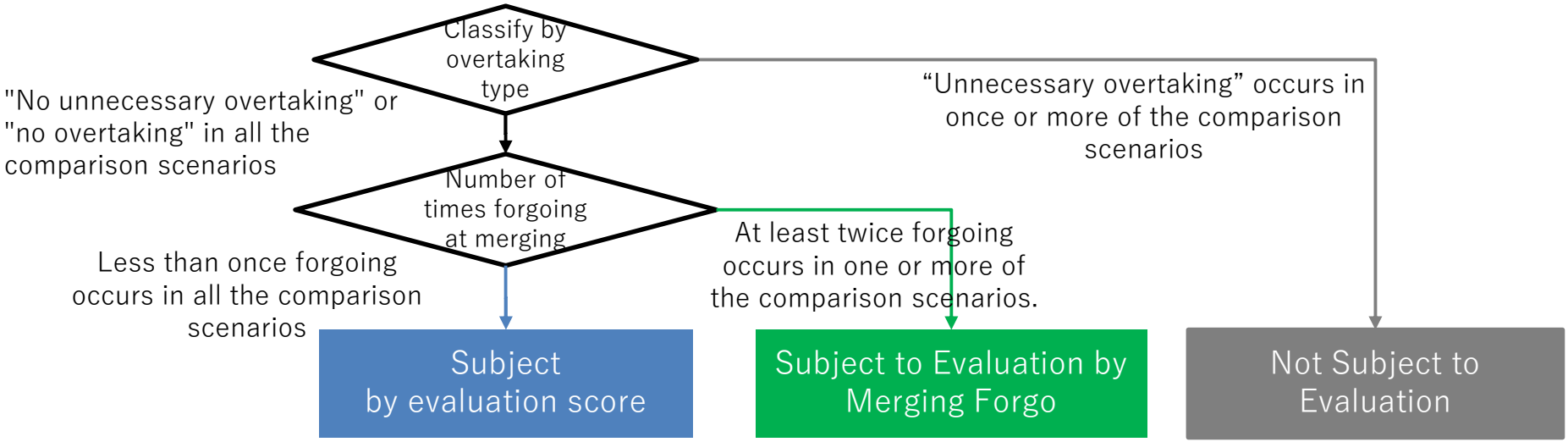
How to Score the points in red and yellow area
(1) Determine the vertical axis based on the relative speed.
(2) Linearly interpolate between the function of 100 points (boundary between blue and yellow) and the function of 0 points (boundary between yellow and red) so that they are equally divided according to the gap distance between vehicles.
(Example): If the relative speed is 25 km/h, the gap distance between vehicles that results in 0 points is 47.7 m, and the distance between vehicles that results in 100 points is 30.1 m. The amount of change in evaluation points per unit distance is 5.682 [points/m], and the distance of 39 m is evaluated as 50 points.

※1 15m：About 3 vehicle lengths
※2 25m： About 1 section of expressway parcel line (dashed line) + 1 vehicle length
※3 H28 "Research Study on Appropriate Vehicle Spacing on Expressways." Referenced by the Highway Research Foundation.
※4 Taken from ISO definition ACC maximum deceleration Maximum braking control by Adaptive Cruise Control

2-1. Definition of good or bad merging behavior To use/not to use evaluation scores during analysis

- Classification method of vehicles to be evaluated by simulation result evaluation type

Classification flow of vehicles to be evaluated

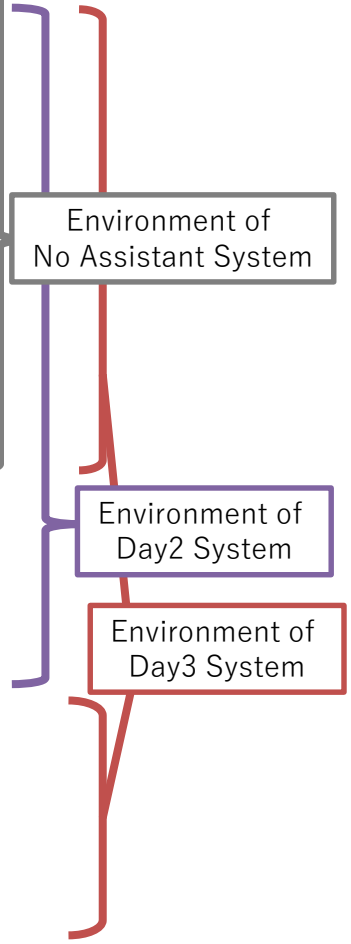


- The merging where the merging vehicle forgoes main lane vehicle at least twice.
  - The evaluation score can be 0 or more even though it might not be a good merging.
  - Such merging should be evaluated by merging forgoes as it cannot be properly evaluated by evaluation score.
- The merging where merging vehicles overtakes main lane vehicle unnecessarily at the merge.
  - Overtaking a main lane vehicle at a merge might be happen due to a side effect of behavior adjustment in the simulation environment.
  - Such merging is excluded from the evaluation since that kind of behavior is not intended originally intended.

2-2. Construction of Simulation Environment Overall model

- Five models shown in the table below were built as simulation environments to confirm the effectiveness of the Day 2 and Day 3 systems.

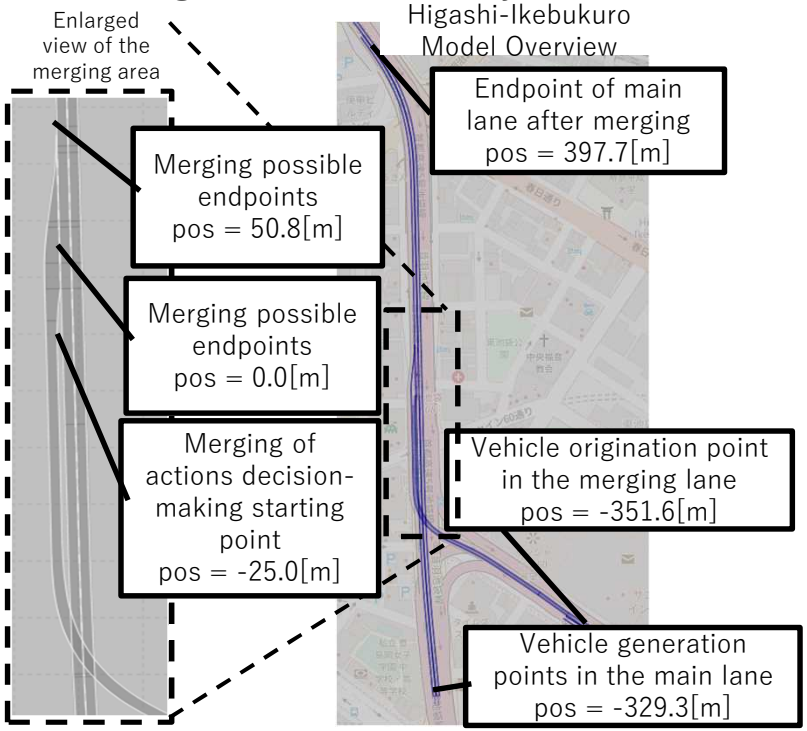
#	Name	Summary	Construction date and source
1	Higashi-Ikebukuro Model	A model that reproduces the road structure, incoming vehicles, and merging behavior for the Higashi Ikebukuro Entrance.	Constructed using the vehicle track data at the Higashi-Ikebukuro Entrance created by the METI SAKURA Project prior to this project.
2	Upstream Model	Model reproduces acceleration/deceleration and lane changes up to 240 m upstream of the main lane at the merging point.	Constructed using vehicle trajectory data acquired by installing cameras at the Higashi-Ikebukuro Entrance as part of the FY2022 initiative.
3	Model with AD vehicles with 2 seconds gaps	Model in which AD vehicles drive with keeping 2-second gap between self and the vehicle in front.	Specification review and construction during FY2022 efforts.
4	Day2 system Model	Model to reproduce the mechanism of “Assistance for merging lane AD vehicles in targeting gaps between main lane vehicles”.	Specification reviewed and built during FY2021 effort; specifications updated during FY2022 effort
5	Day3 System Model	Model to reproduce the mechanism of “Assistance for merging lane AD vehicles in targeting gaps between main lane vehicles” and “Assistance for main lane AD vehicles to coordinate”.	Specification reviewed and built during FY2021 effort; specifications updated during FY2022 effort



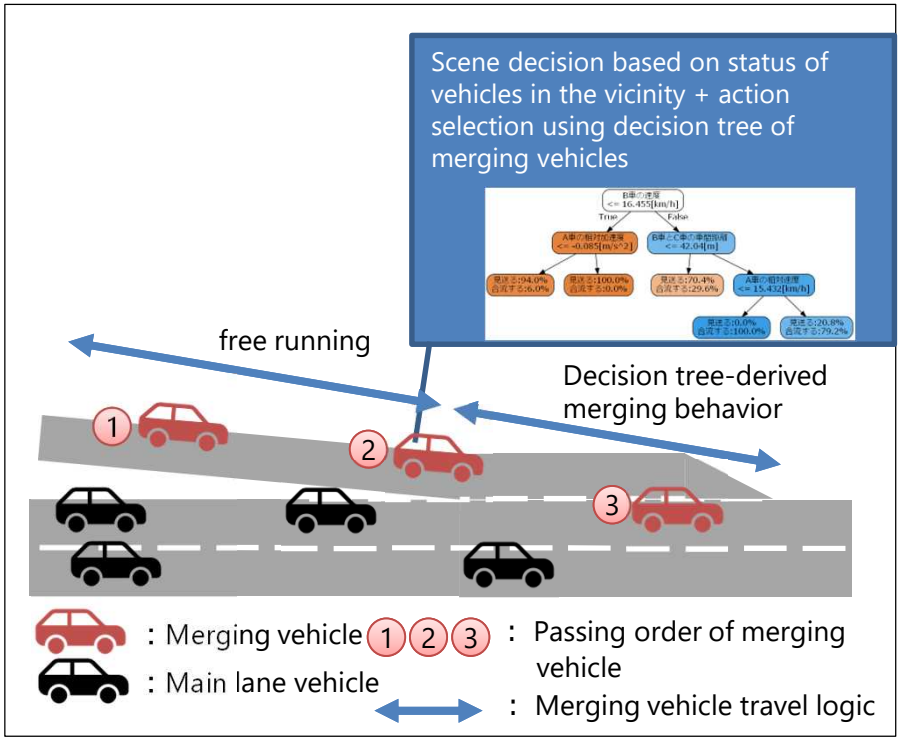
2-2. Construction of Simulation Environment #1：Higashi-Ikebukuro Model

- A model reproducing the road structure, incoming vehicles, and merging behavior at the Higashi-Ikebukuro Entrance on the traffic simulator "Vissim".
  - Constructed before this project based on the trajectory data obtained by the SAKURA Project of METI
- Reproduced the following items from road alignment and actual vehicle trajectory data
  - The number of vehicles that occur upstream of the main lanes and merging lane
  - Travel speeds of main lane and merging lane vehicles
  - Gap distance between self and the vehicle in front
  - Merging behavior of merging vehicles (decision tree model learned using machine learning, etc.)

Road alignment of the subject site

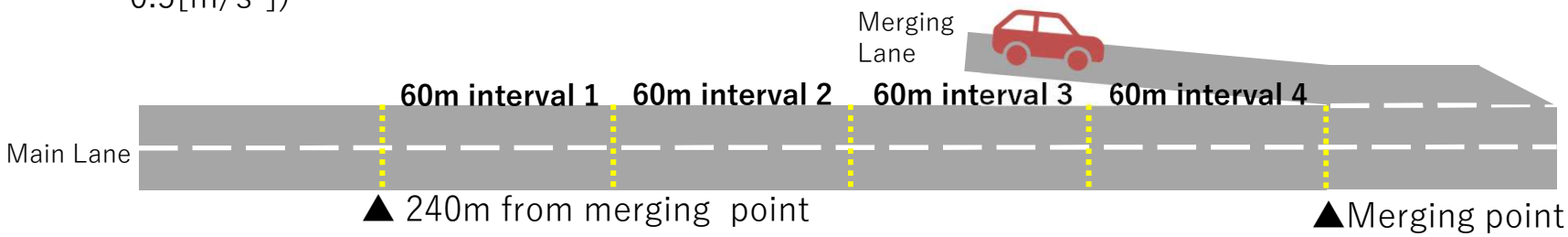


Running behavior of merging vehicles in the Higashi Ikebukuro model



2-2. Construction of Simulation Environment #2：Upstream Model

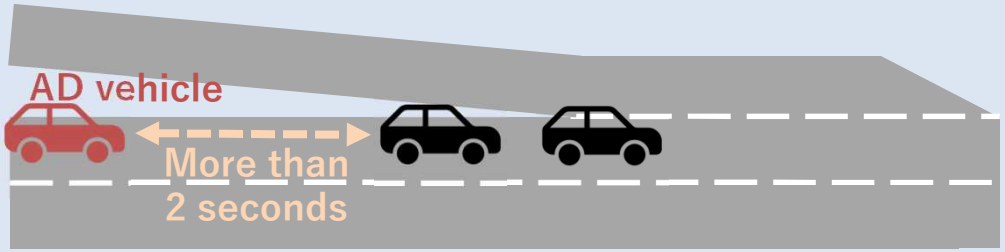
- A model reproduces acceleration/deceleration and lane change behavior from merging possible endpoints to 240m upstream of the main lane.
- The model was constructed using vehicle trajectory data obtained by installing cameras newly in this FY at the Higashi-Ikebukuro Entrance in order to refine the driving behavior of the upstream portion of the main lane.
- Based on the obtained vehicle trajectory data, the following are reproduced.
  - Lane change probability (from left to right lane)
  - Lane change probability (from right to left lane)
  - Probability of vehicles tending to decelerate (Average acceleration in the interval is less than -0.5[m/s^2])



	60m interval 1	60m interval 2	60m interval 3	60m interval 4
Frequency of changes to right lane	0.2%	0.4%	1.0%	0.6%
Frequency of changes to left lane	0.2%	0.4%	0.8%	0.2%
Deceleration Trend Vehicle Frequency	0.6%	0.4%	0.2%	9.7%

2-2. Construction of Simulation Environment
#3：Model with AD vehicles with 2 seconds gaps

- A model in which AD vehicles drive with keeping 2-second gap between self and the vehicle in front
- This model reproduces the AD vehicle's margin of safety compared to a vehicle driven by a general driver.
  - To verify the effect of merging improvement by mixing vehicles that keeps 2 seconds between vehicles



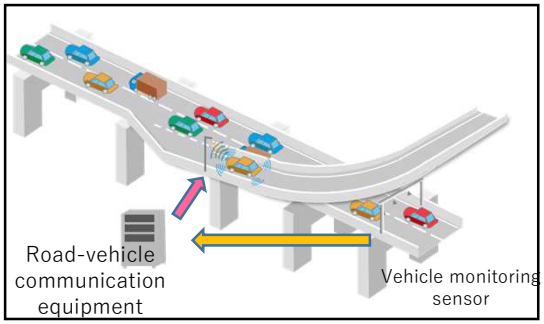
Model with AD vehicles spacing 2 seconds between vehicles

AD vehicles drive with a 2-second gap from the vehicle in front

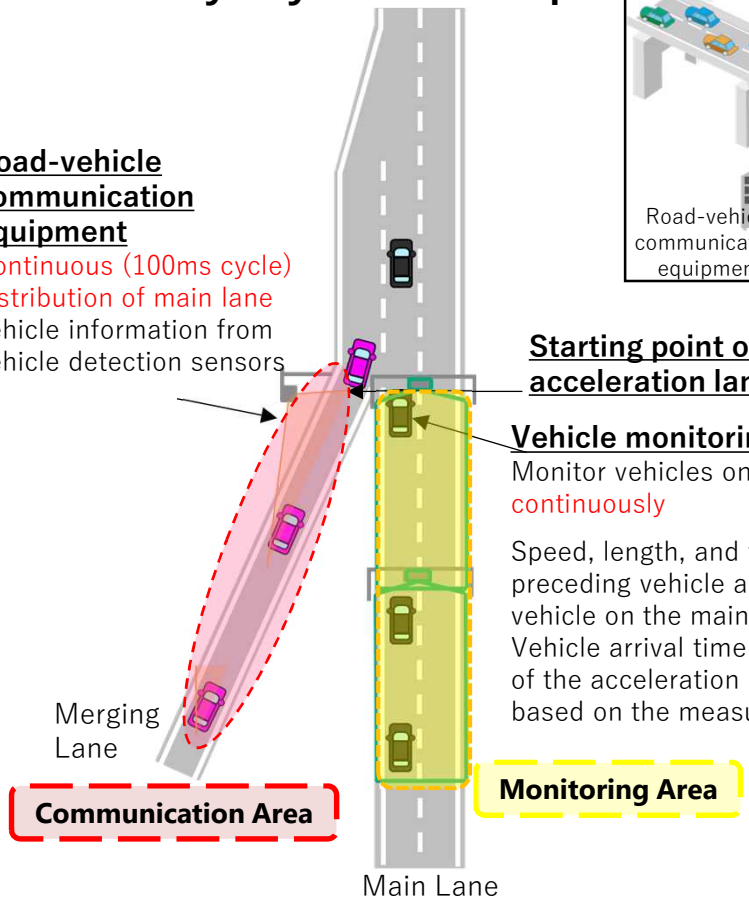
2-2. Construction of Simulation Environment #4：Day2 System Model（1/2）

- A model that reproduces the "Assistance in targeting gaps between main lane vehicles" provided by the Day2 system
- The movements of vehicles are acquired continuously on the main lane, and the information is provided continuously to merging AD vehicles
  →Merging vehicles adjust their speed so as not to be side-by-side with main lane vehicles

The Day2 system concept



Road-vehicle communication equipment
Continuous (100ms cycle) distribution of main lane vehicle information from vehicle detection sensors

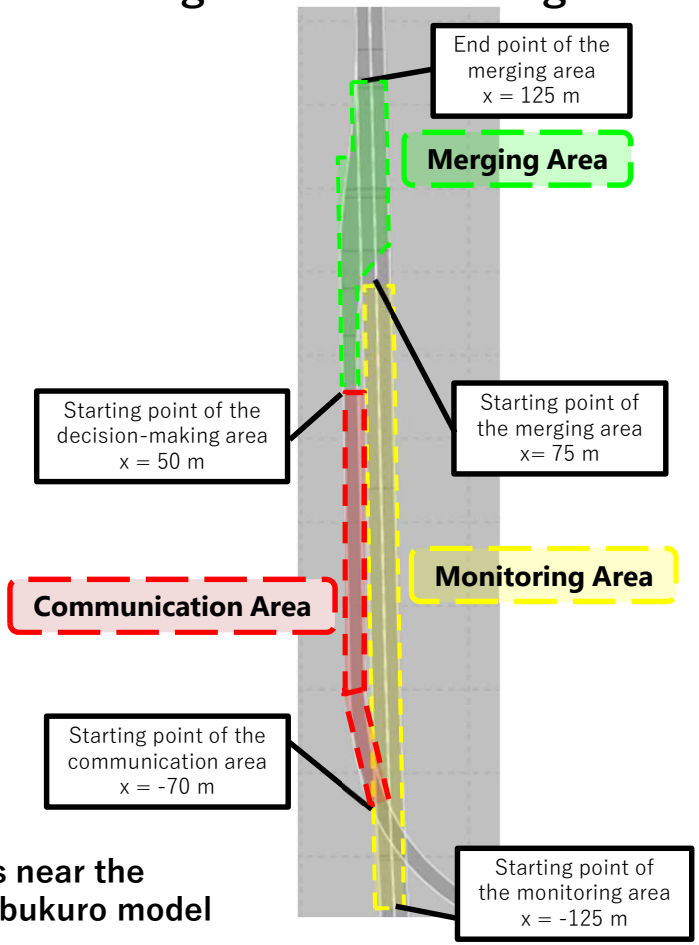


Starting point of acceleration lane

Vehicle monitoring sensor
Monitor vehicles on the main lane continuously

Speed, length, and the gap time from the preceding vehicle are measured for each vehicle on the main lane
Vehicle arrival time at the starting point of the acceleration lane is forecasted based on the measurements

Road alignment at the target site



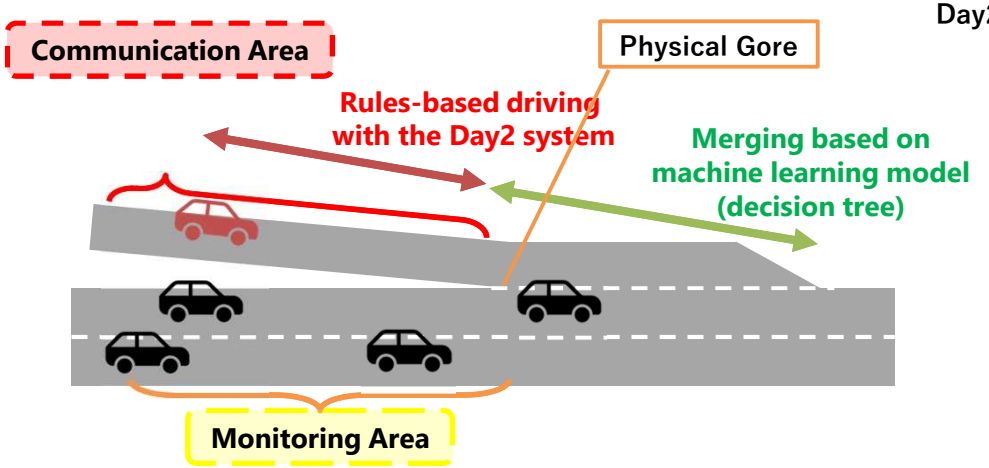
Divided into three sections near the merging of the Higashi Ikebukuro model according to the concept.

2-2. Construction of Simulation Environment #4：Day2 System Model（2/2）

- The details of the information provided by Day2 system to merging vehicles, and the behavior of merging vehicle which is informed that, are defined as below

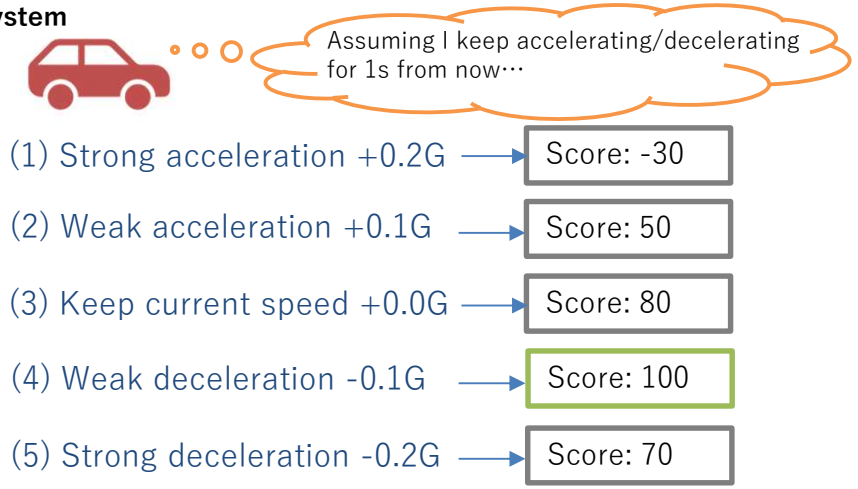
	Details
Information provided by Day2 system to merging vehicles	• The information of the positions and speeds of main lane vehicles running the monitoring area are obtained. • Based on the information above, estimated times of arrival to the physical gore for each vehicles are notified. • These processes are executed every 100ms.
Informed merging vehicle behavior	• Merging vehicle considers five action options when informed: strong acceleration, weak acceleration, no acceleration/deceleration, weak deceleration, and strong deceleration. • For each action, predict the state when the merging vehicle reaches at the physical gore assuming the action is taken in the next 1 second. • The action with the highest evaluation score is selected.

Provide information to merging vehicles by the Day2 system



- Measure position and speed of each vehicle on the main lane
- Inform the merging vehicle about the estimated arrival time of the vehicles on the main lane at the starting point of the merging area

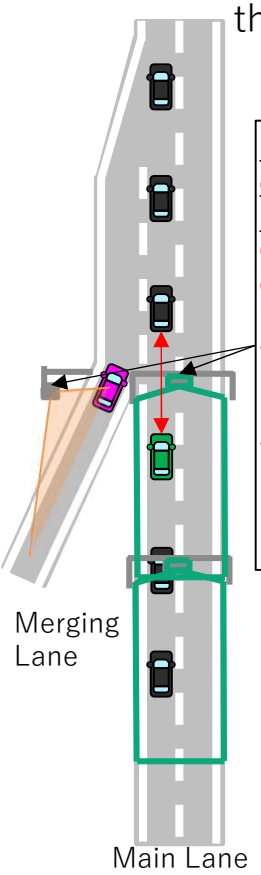
Driving behavior of a merging vehicles with information provided by the Day2 system



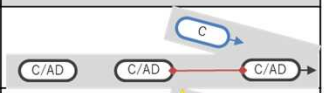
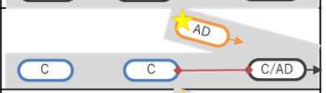
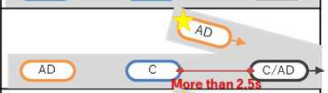
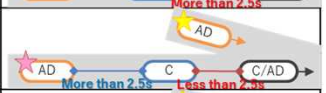
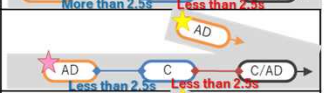
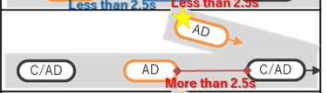
The vehicle selects option (4) “Weak deceleration -0.1G” at the next time step, which gives the best score

2-2. Construction of Simulation Environment #5：Day3 System Model

- A model reproduces the "Assistance for main lane AD vehicles to coordinate" provided by the Day3 system.
- In addition to Day2 system, Day3 system reproduces the merging instruction from the roadside to main lane vehicle.
  - Main lane vehicles keep or increase the gap between vehicles in front of them about 2.0 seconds up to 2.5 seconds at maximum.
  - At the start of the assistance, one situation is selected from the default seven situations, and the AD merging vehicle and AD main lane vehicle behaves according to the selected situation.



Road-vehicle communication equipment & Vehicle monitoring sensor
Continuous detection and distribution of main lane and merging lane vehicles
- Merging vehicles accelerate and decelerate to adjust the time to reach the merge
- Main lane vehicles decelerate to increase the gap between vehicles in front from 2 seconds up to 2.5 seconds

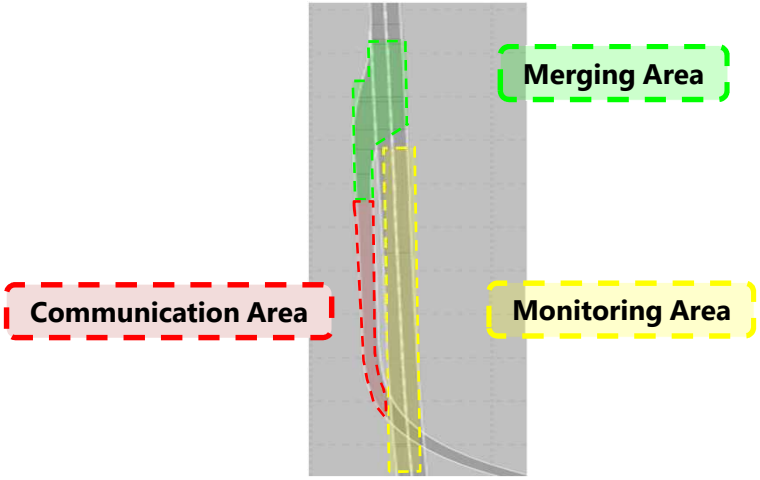
#	Kind of vehicles: Merging	Kind of vehicles: First car following the main line	Kind of vehicles: Second car following the main line	Red line gap	Blue line gap	Assistant for merging car	Assistant for main lane car	Target for assistant	Diagram of the projected confluence (Assuming **all vehicles move at constant velocity**)
①	Conventional	-	-	-	-	Not do	Not do	-	
②	AD	Conventional	Conventional	-	-	Do	Not do	-	
③	AD	Conventional	AD	More than 2.5 seconds	-	Do	Not do	-	
④	AD	Conventional	AD	Less than 2.5 seconds	More than 2.5 seconds	Do	Keep more than 2.5 seconds between vehicles	Second car following the main line	
⑤	AD	Conventional	AD	Less than 2.5 seconds	Less than 2.5 seconds	Do	deceleration indication	Second car following the main line	
⑥	AD	AD	-	More than 2.5 seconds	-	Do	Keep at least 2.5 seconds between vehicles	-	
⑦	AD	AD	-	Less than 2.5 seconds	Less than 2.5 seconds	Do	deceleration indication	First car following the main line	

※ "-"：Unnecessary condition, ★: Assistant target for merging vehicles, ★: Assistant target for main lane vehicles, ◆—◆: Target gaps

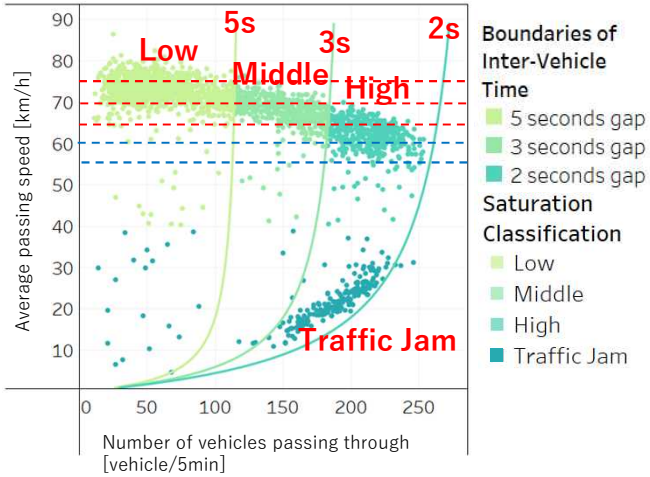
2-3. Analysis scenario
Combination of communication area and monitoring area length

- Combinations of communication area and monitoring area length are shown in table below. Each combinations are calculated from the main lane speeds in the traffic counter data assuming the range of traffic density that can be covered by the assistance.

Location of each area



Higashi-Ikebukuro Q-V diagram and main lane time distribution between vehicles

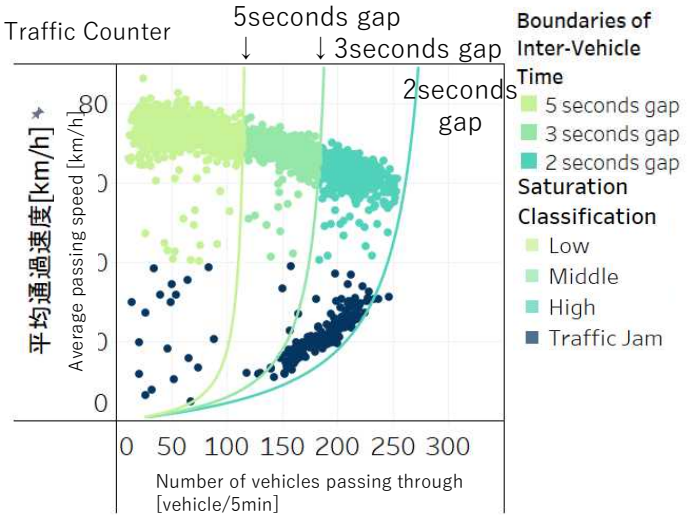


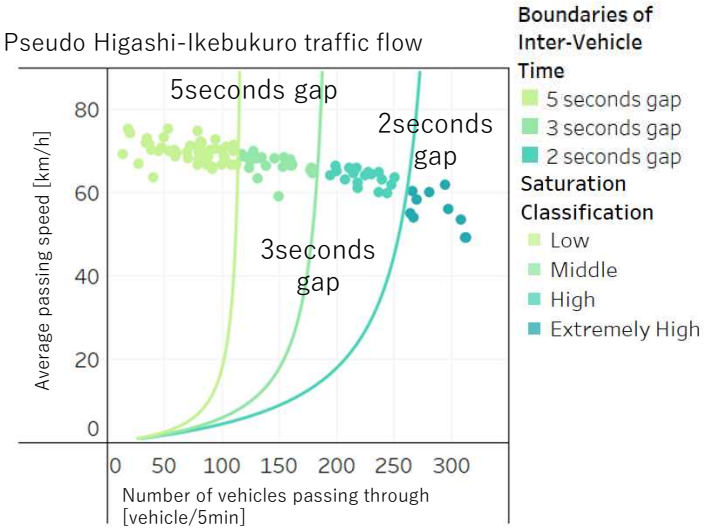
Parameter combination during simulation (assistant area design from Q-V diagram)

main lane average speed [km/h]	Merging average speed [km/h]	Communication Area [m]	Monitoring Area [m]	Remarks
75	51	**130**	**240**	Covered up to low traffic saturation (Assistant efficiency is not good due to the large time between vehicles.)
70	51	**120**	**210**	Covered up to medium traffic saturation (Most efficient assistant effects)
65	51	**110**	**180**	Covered up to high traffic saturation (Most efficient assistant effects)
60	51	**90**	**150**	Covered up Traffic saturation high 1/2~1/3
55	51	**80**	**130**	Physical limitations expected to be less effective

2-3. Analysis scenario
Definition of traffic saturation

- To calculate the effect of merging assistant system for each main lane traffic flow in the FY2022 analysis, the main lane is classified into four levels of saturation depending on the congested conditions of main lane , from low saturation to extremely high saturation.
- The numbers of vehicles generated per saturation level are determined based on traffic counter data





Saturation	Number of Merging Vehicles Generated per Hour	Number of Main Vehicles Generated per Hour
Low	20～140	100～700
Middle	140～220	700～1100
High	220～300	1100～1500
Extremely High	300～360	1500～1800

2-4. Notes on the analyses

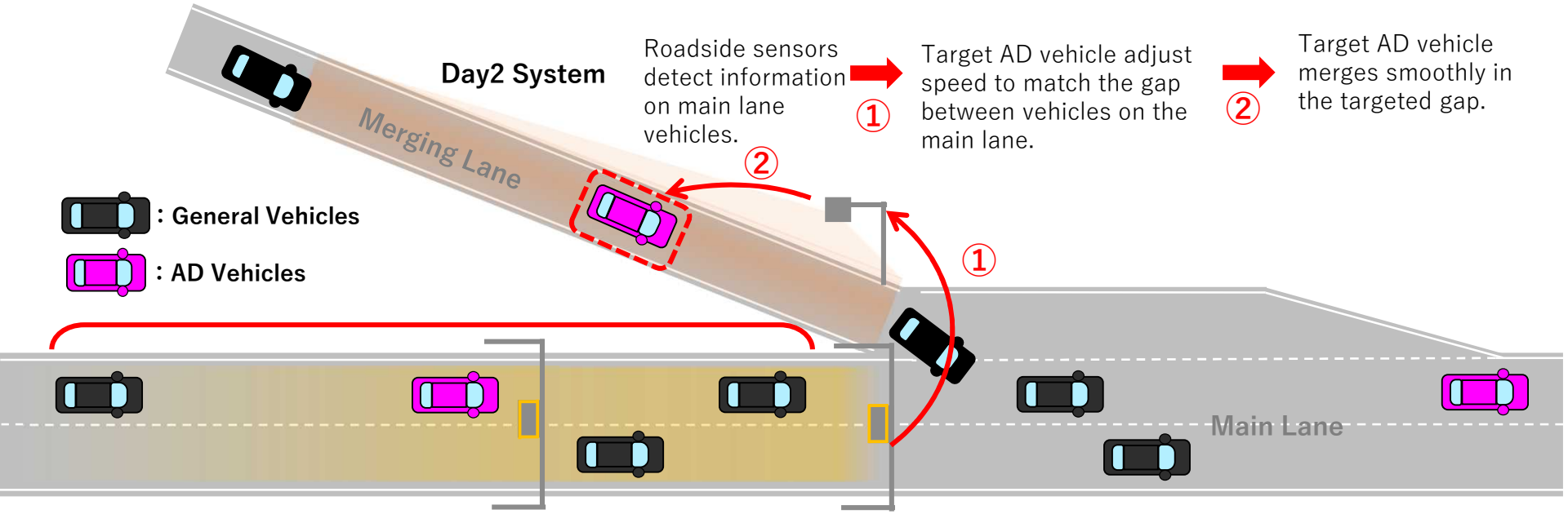
- Points to note for each model are as follows

Item	Details
Locations analyzed by simulation	The Higashi Ikebukuro Entrance on the off-ramp of Ikebukuro Line of the Metropolitan Expressway No.5
Definition of good or bad merging behavior and Effects of merging improved	Definition of evaluation points was determined through discussions within the Simulation Practitioners Meeting within the project. Verify the effect of merging improvement by comparing evaluation points between scenarios.
Classification the degree of margin for merging according to the evaluation scores and the feasibility of the concept	Classification the degree of margin for merging according to the evaluation scores was determined through discussions within the Simulation Practitioners Meeting within the project. Verify the feasibility of the concept based on the frequency of “Merging without enough space.”
Gaps between AD vehicle and vehicles in front of it	Allow at least 2.0 seconds gaps
Frequency of determining the change in behavior of merging vehicles in the Day 2 and Day 3 system models	Once every 100 ms
Predicted time of arrival at the starting point of merging in the main lane vehicle in Day2 system	Assuming acceleration/deceleration in the range of -0.2G to +0.2G for 1 second
Gaps between the main lane AD vehicle and the vehicle in front of it in Day3 system	Expand the minimum time between vehicles to be maintained from 2.0 seconds to 2.5 seconds
Vehicles generated in the simulation	Only ordinary cars
Merging behavior during traffic flow with extremely high saturation	This is a flow rate that cannot occur in the actual traffic flow at the analyzed location. Therefore, it is outside the learning range of the decision tree algorithm for merging behavior, and the reproducibility of the merging behavior has not been verified.

3. Day2 System Verification

3-1. Verification of the Feasibility of the Day2 System Concept

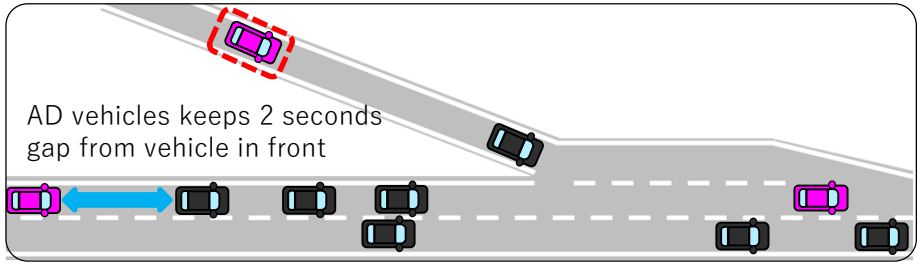
- Verify the effect how the merging is improved by installing the Day2 system, and the feasibility of the concept.
- Hypothesis
  - Merging should be improved by the information of the main lane vehicles are distributed to the AD vehicle on merging lane then it adjusts speed in advance to merging.
  - The effect was particularly significant when merging vehicles and main lane vehicles were side-by-side at the merge point.
- Verification Method
  - Evaluate results of scenarios without assistant system and with Day2 system installed
    - Mixing rate of AD vehicles: 20%.
    - Used traffic flow : Pseudo-Higashi-Ikebukuro traffic flow (p. 18)



3-1. Verification of the Feasibility of the Day2 System Concept Behavior of AD Vehicles with Merging Assistance

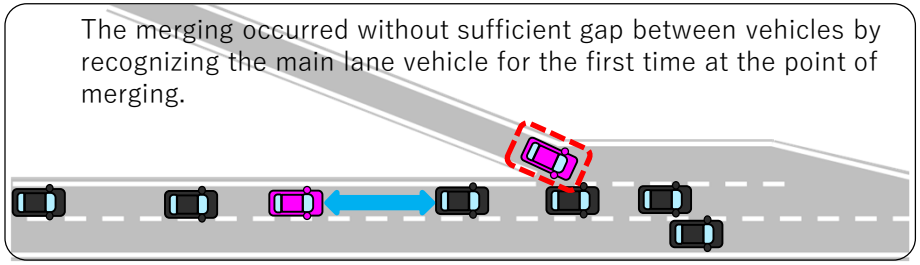
- Examples of merging improved by the installation of the Day2 system are as follows.

Before merging



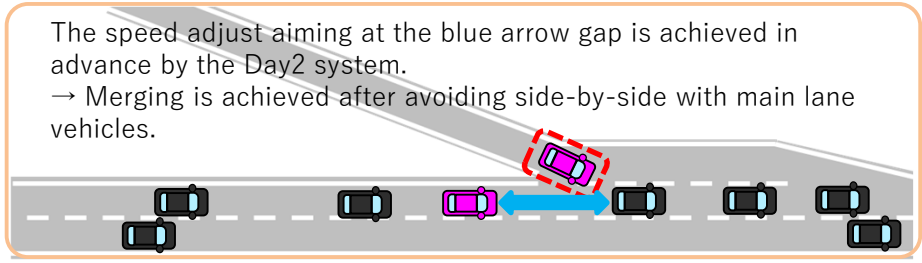
Without Assistant System

：Evaluation score rated as "Merging without enough space".



Day2 System

：Assist merging vehicles to avoid being side-by-side with main lane vehicles



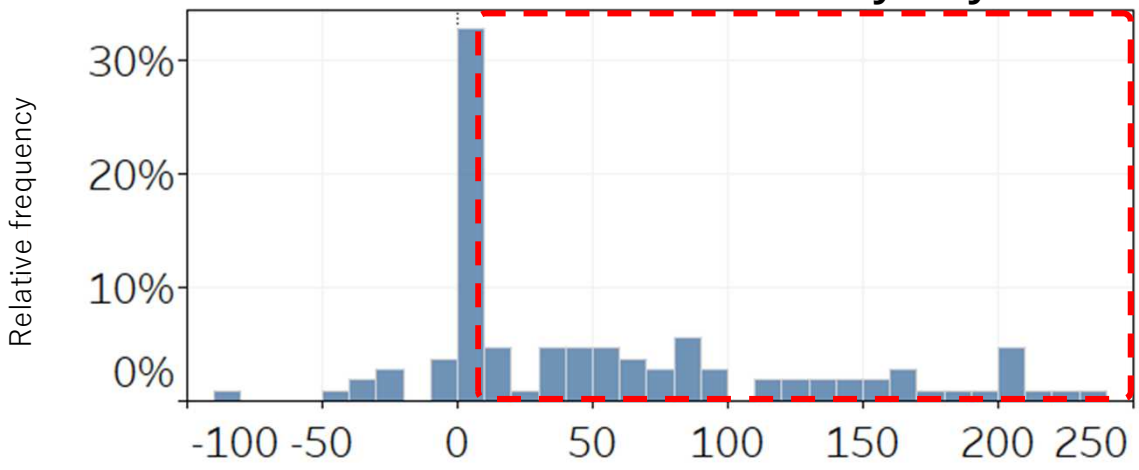
Without assistant system, merging vehicles would have been side-by-side with main lane vehicles at the point of merging, can avoid side-by-side and merge with the assistance of the Day 2 system.

→ The merging was rated as "Merging with enough space," and merging improved significantly.

3-1. Verification of the Feasibility of the Day2 System Concept Improvement Effect for Merging

- The effect of the merging improvement was evaluated by the distribution of the change in evaluation score associated with the installation of the Day2 system.

A large percentage of merging AD vehicles have improved their rating points with the installation of the Day 2 system.



The range of improvement in evaluation scores

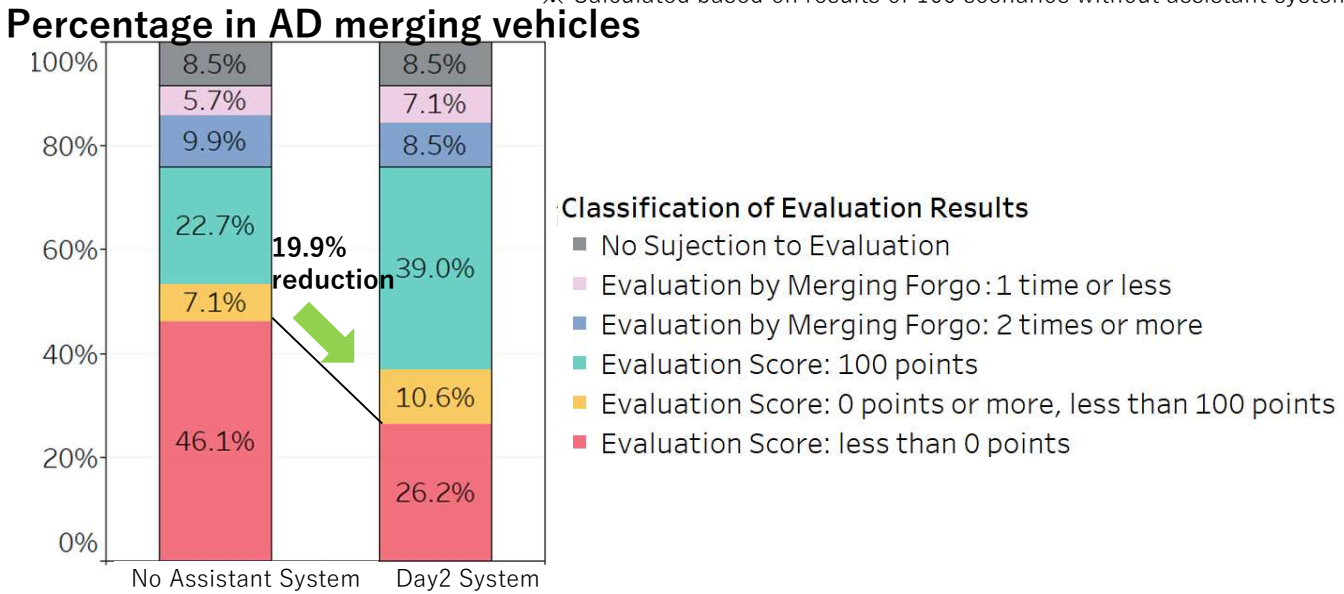
Many AD vehicles are improved the evaluation score by installing the Day2 system, some are improved 100 points or more.
-> **The Day2 system is highly effective to improve merging.**

3-1. Verification of the Feasibility of the Day2 System Concept Conceptual Feasibility

- The concept feasibility was evaluated based on the criterion "Ratio of vehicles with an evaluation score of less than 0(“Merging without enough space”) to the total number of vehicles subject to evaluation (A).”

Percentage improvement of A over no assistant system scenario ＞**21.3%**(※)

※ Calculated based on results of 100 scenarios without assistant system



Evaluation Point	Merging Evaluation Score	Merging Forgo Evaluation
Percentage of merging AD vehicle evaluation results	Percentage of “Merging without enough space” decreased by 19.9% (**Improvement rate 43.0%**)	No significant change

The merging is no longer evaluated as "Merging without enough space"

The Day2 system reduced the number of vehicles “Merging without enough space” to spare about half.

-> **The concept of the Day 2 system was confirmed to be feasible.**

3-2. Verification of the Effect of Merging Improvement When System Physical Conditions are Changed （1/2）

- We verified the system physical conditions required for the Day2 system to be implemented in society.
- Verification Method
  - We evaluated the results of scenarios in which each of the following physical conditions was modified.
    - Length of monitoring area/communication area
    - Transmission time of main lane vehicle information
    - Main lane vehicle location error
    - Main lane vehicle speed information error
  - The results were evaluated for each scenario of the total combination of the above physical conditions
    - Mixing rate of AD vehicles: 20%.
    - Used traffic flow : Pseudo-Higashi-Ikebukuro traffic flow (p. 18)

※The evaluation was conducted using an index that integrates the evaluation point rating and the forgoing rating, with an evaluation based on the percentage of improvement relative to the no assistant system scenario.

3-2. Verification of the Effect of Merging Improvement When System Physical Conditions are Changed （2/2）

- The results for each of the system physical conditions were compared as follows.

Physical Conditions of the Assistant System	Impact on Assistant System Effectiveness
Location Error (m) 0/-1~1 Uniform distribution with the above range as upper and lower limits	The assistant effect of Day2 system was not affected by the presence or absence of location error.
Monitoring / Communication Area (m) 240・130/210・120/ 180・110/150・90/130・80	The longer the monitoring / communication range available, the more effective the assistant.
Transmission Time of Information (s) 0/0.4/0.8/1.3 Normal distribution with standard deviation 0.2 with the above as the mean	The faster the transmission time, the greater the assistant effect.
Speed Information Error (km/h) 0/-6~6/-12~12/-12~0 Normal distribution with the above range as the 95% interval	Smaller errors basically increase the assistant effect.

3-2. Verification of the Effect of Merging Improvement When System Physical Conditions are Changed （Evaluation of Feasibility）

- Verified the range of system physical conditions under which the Day 2 system concept is feasible.

※The numbers [%] in the table represent the percentage improvement over the no assistant system scenario for the number of units that will “Merge without enough space” to spare.

※The criterion for feasibility was defined as **the improvement rate > 18.6%** based on the results of 100 runs of the scenario without the assistant system.

Speed Information Error † (s)	Transmission Time of Information*(km/h)	Monitoring / Communication Area(m)				
		130/80	150/90	180/110	210/120	240/130
1.3	-12~0	-11.53%	-12.79%	-10.17%	-9.23%	-9.70%
	-12~+12	4.26%	11.38%	15.68%	16.08%	17.70%
	-6~+6	7.12%	13.03%	**21.46%**	18.05%	14.12%
	0	8.49%	11.90%	17.40%	17.75%	**20.45%**
0.8	-12~0	2.65%	10.07%	16.84%	18.29%	15.55%
	-12~+12	16.61%	18.32%	**26.67%**	**29.13%**	**28.18%**
	-6~+6	**19.75%**	**24.29%**	**29.28%**	**28.25%**	**31.31%**
	0	**20.44%**	**23.64%**	**30.30%**	**26.62%**	**26.67%**
0.4	-12~0	**18.96%**	**23.39%**	**25.49%**	**22.20%**	**28.32%**
	-12~+12	**24.26%**	**21.49%**	**27.74%**	**29.21%**	**29.05%**
	-6~+6	**22.48%**	**24.92%**	**27.93%**	**27.25%**	**31.12%**
	0	**27.36%**	**26.93%**	**26.25%**	**28.36%**	**28.61%**
0	-12~0	**22.83%**	**25.21%**	**29.21%**	**26.52%**	**32.20%**
	-12~+12	**23.49%**	**24.88%**	**24.78%**	**24.17%**	**30.27%**
	-6~+6	**27.56%**	**26.16%**	**30.94%**	**32.79%**	**35.68%**
	0	**27.19%**	**28.74%**	**30.05%**	**29.97%**	**32.11%**

† Normal distribution with mean value and standard deviation of 0.2
*Normal distribution with the 95% interval in the relevant range

Not feasible

Feasible

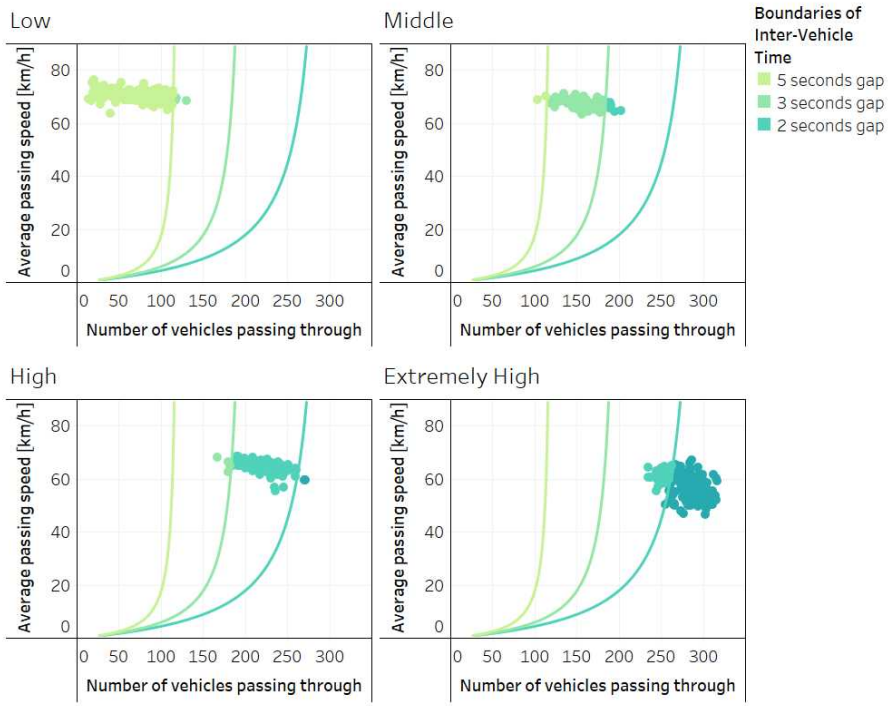
The merging is no longer evaluated as "Merging without enough space"

The better the physical conditions other than position error, the less marginal merging was observed.
The improvement rate was significantly reduced when there is a delay of 1.3s.
-> **The concept of the Day 2 system in the red indicated area was confirmed to be feasible.**

3-3. Verification of the Effect of Merging Improvement When Traffic Flow Conditions are Changed

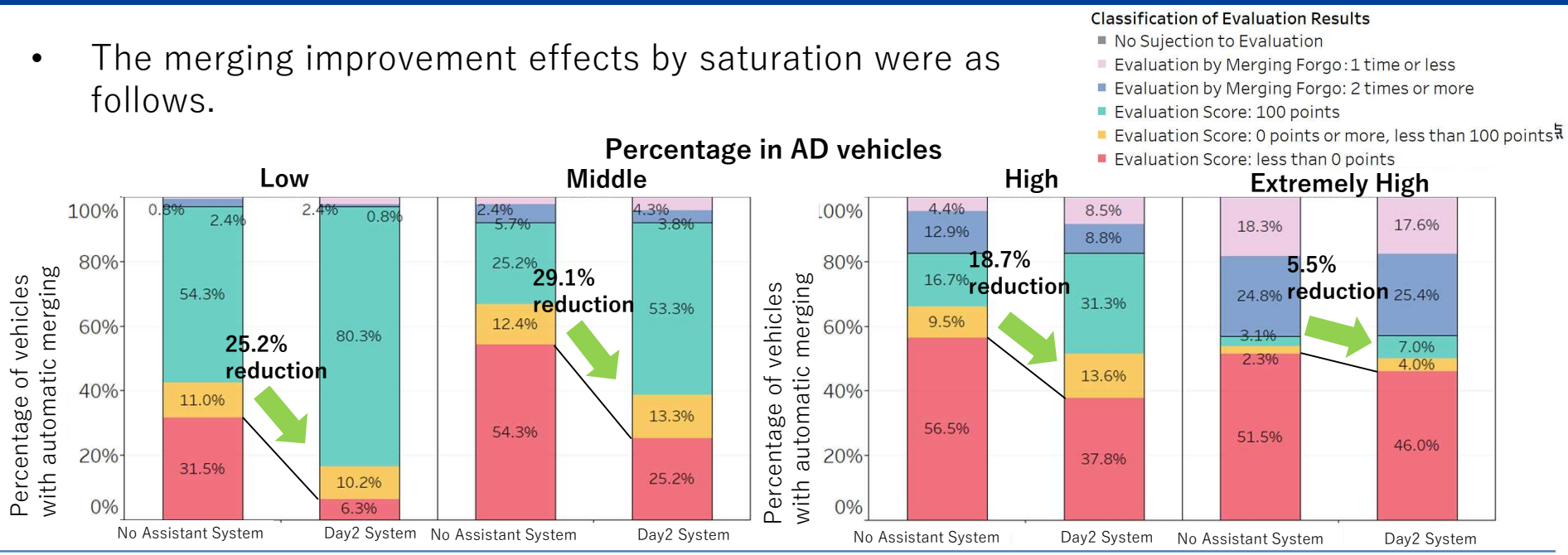
- The impact of changing traffic flow conditions on the effectiveness of the Day 2 system in merging assistance was examined.
- Hypothesis
  - Since the Day 2 system encourages merging AD vehicles to merge into the main lane with room to spare, the merging effect depends on the density of the main lane traffic flow.
  - When the main lane traffic flow is dense, there are fewer gaps available, and the merging improvement effect is reduced.
- Verification Method
  - Results were compared for each traffic saturation scenario for low, medium, high, and extremely high saturation.
    - Mixing rate of AD vehicles: 20%.
    - Used traffic flow：Traffic flow at each saturation level

Saturation	Number of Merging Vehicles Generated per Hour	Number of Main Vehicles Generated per Hour
Low	20～140	100～700
Middle	140～220	700～1100
High	220～300	1100～1500
Extremely High	300～360	1500～1800



3-3. Verification of the Effect of Merging Improvement When Traffic Flow Conditions are Changed

- The merging improvement effects by saturation were as follows.



Evaluation Point	Merging Evaluation Score	Merging Forgo Evaluation
Effect of improved the merging	• Percentage of “Merging without enough space” decreased the most in middle saturation (29.1%) • Smallest impact in extremely high saturation (about 5%)	• The percentage of merging foregone twice or more increased as saturation increased.

The merging is no longer evaluated as "Merging without enough space"

The number of “Merging without enough space" cases improved by the Day 2 assistant increased in the order of saturation medium > low > high > extremely high. In the case of low saturation, the Day2 assistant reduced the number of “no margin merging" to about 5% of the merging AD vehicles.

-> The concept of the Day 2 system in the low, middle and high saturation category were confirmed to be feasible.

4. Feasibility of the Day 3 System Concept

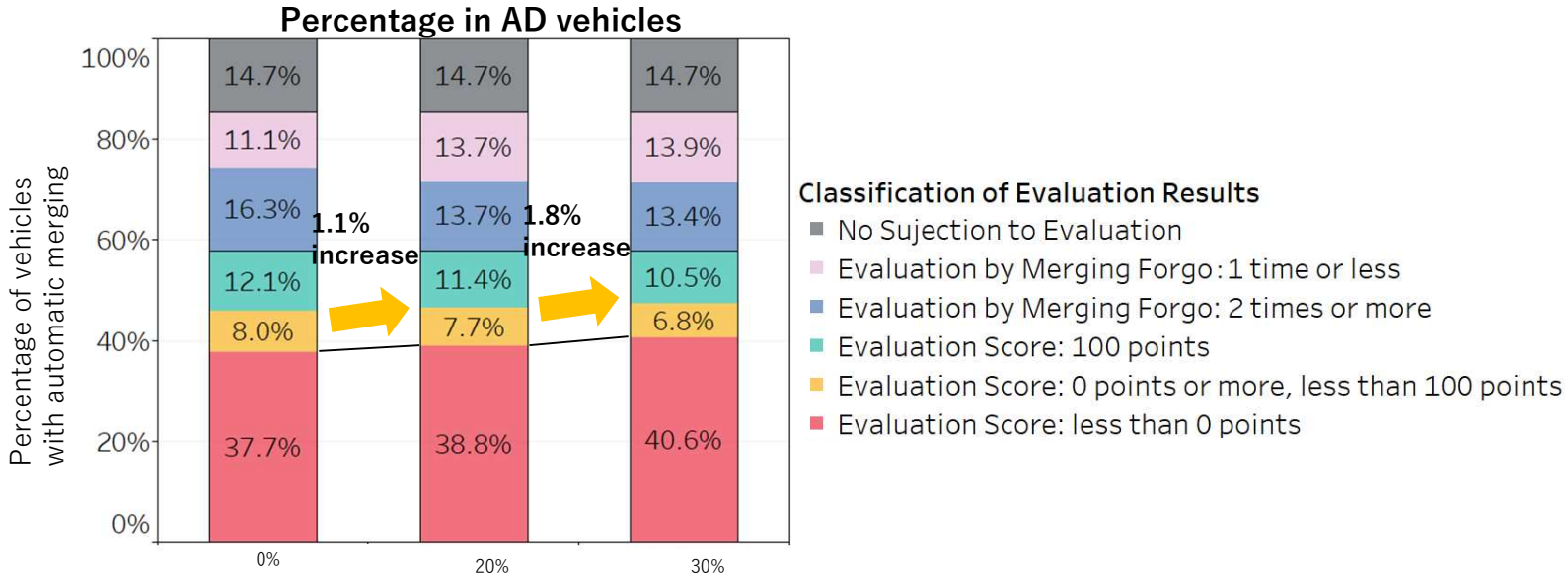
4-1. Impact of Changes in the Mixing Rate of AD Vehicles on the Effectiveness of Assistant Systems

- The Day3 system is designed to be implemented in a society where the mixing rate of AD vehicles is about 30%.
- We simply evaluated the impact on merging when the AD vehicle mixing rate changes.

- Hypothesis
  - Increasing the number of AD vehicles will increase the average time between vehicles on the main lane and improve merging.
    - AD vehicles drive in such a way that they have 2 seconds between vehicles in front of them.
- Verification Method
  - Comparison of results for no assistant system scenarios with different AD vehicle mixing rates
  - Mixing rate of AD vehicles : 0%, 20%, and 30%.
  - Used traffic flow : Traffic flow of saturation high

4-1. Impact of Changes in the Mixing Rate of AD Vehicles on the Effectiveness of Assistant Systems

- The effect of merging improvement for each AD vehicle mixing ratio was as follows.



Evaluation Point	Merging Evaluation Score	Merging Forgo Evaluation
Impact of increased mixing rate	Increased “Merging without enough space."	No significant change

The merging is no longer evaluated as "Merging without enough space"

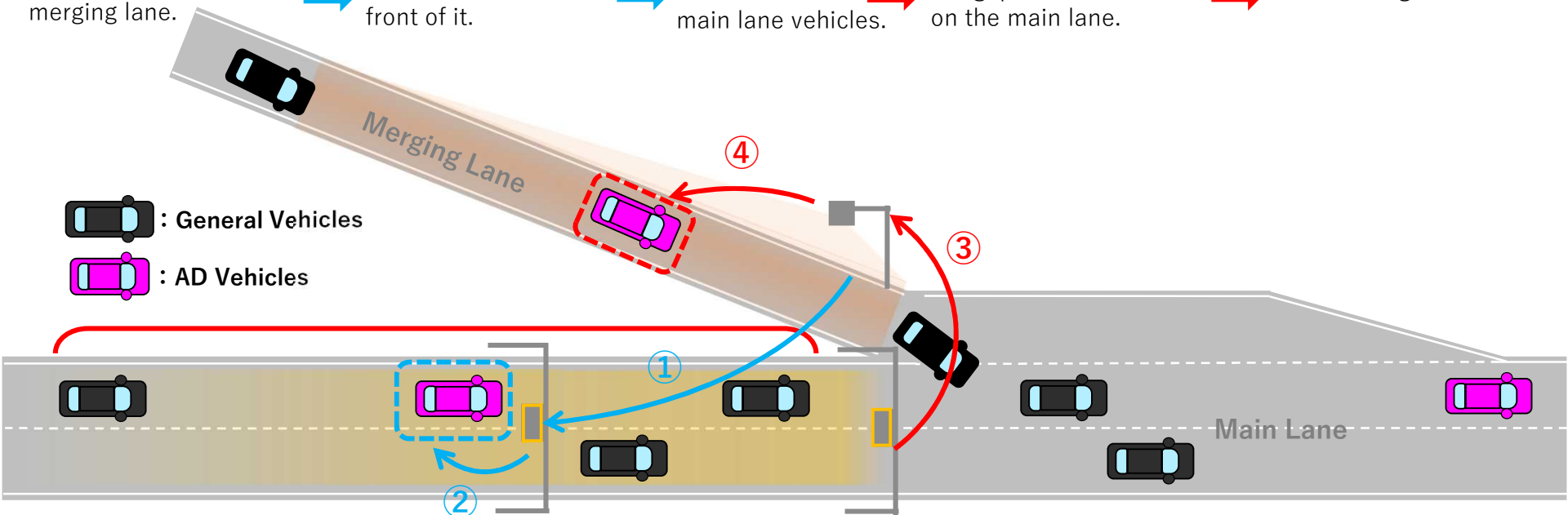
Merging worsens as the AD vehicle mix increases.
→ AD vehicles in the main lane will equalize the gap between vehicles, vehicle convoys below 40 km/h for extended periods of time.

4-2. Verification of the Feasibility of the Day3 System Concept

- The effectiveness of the installation of the Day3 system in improving the merging and the feasibility of the concept was verified.
- Hypothesis
  - Merging will be improved by increasing the gap between the main lane AD vehicle and the vehicle in front.
- Verification Method
  - The results of the scenario with the Day3 system were compared with those of the scenarios without the assistant system and with the scenario with the Day2 system.
    - Mixing rate of AD vehicles : 20% and 30%.
    - Used traffic flow : High saturated traffic flow

Day3 System

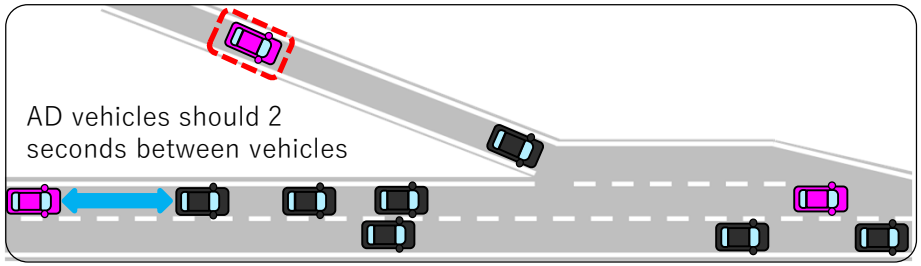
It receives information on AD vehicles in the merging lane. → ① It increases the gap between the vehicle in front of it. → ② It receives information on main lane vehicles. → ③ It adjust speed to match the gap between vehicles on the main lane. → ④ It merges smoothly between targeted vehicles.



4-2. Verification of the Feasibility of the Day3 System Concept Behavior of AD Vehicles with Merging Assistance

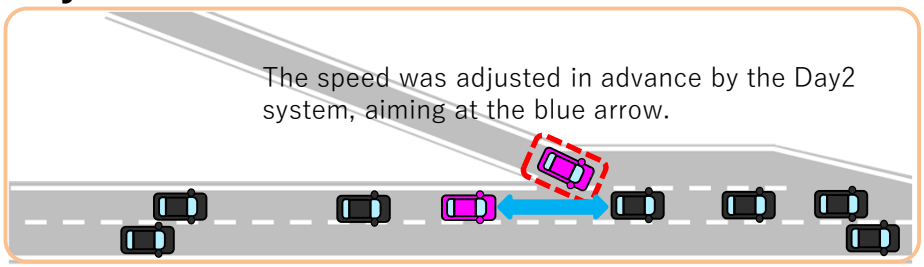
- Examples of mergers improved by the Day 2 and Day 3 systems were as follows.

Before merging



Day2 System

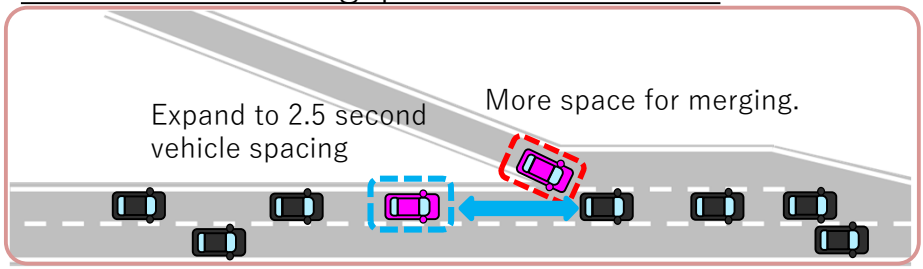
：Assist merging vehicles to avoid being side-by-side with main lane vehicles.



Day3 System

：Assist merging vehicles to avoid being side-by-side with main lane vehicles.

＋ The assistant system for main lane vehicles has increased the gap between vehicles.

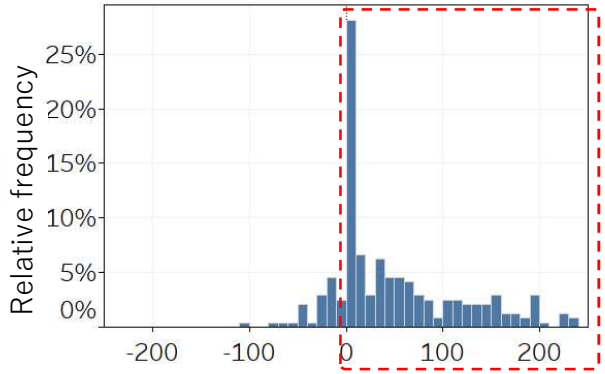


In addition to side-by-side avoidance with main lane vehicles, the Day3 system allows merging into a larger gap between vehicles.

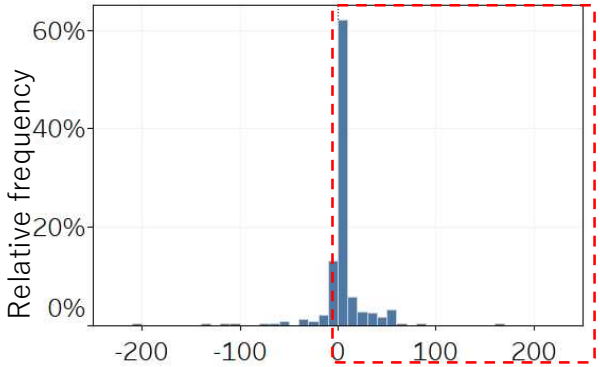
4-2. Verification of the Feasibility of the Day3 System Concept Improvement Effect for Merging

- The effect of the merging improvement was evaluated by the distribution of the change in evaluation points associated with the installation of the Day 3 system.

Mixing rate of AD vehicles: 20%

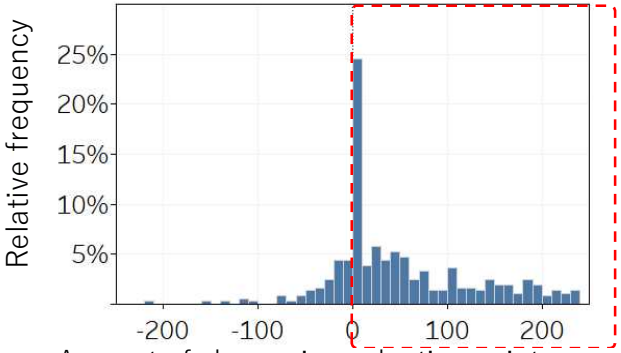


Amount of change in evaluation points associated with the installation of the Day 2 system

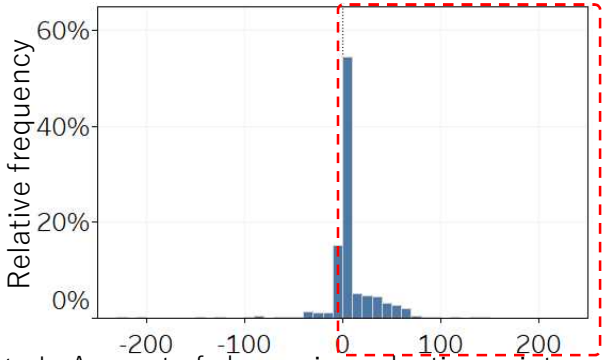


Amount of change in evaluation points associated with the change from the Day 2 system to the Day 3 system

Mixing rate of AD vehicles: 30%



Amount of change in evaluation points associated with the installation of the Day 2 system



Amount of change in evaluation points associated with the change from the Day 2 system to the Day 3 system

The range of improvement in evaluation scores

- By installing Day3 system, the number of AD vehicles that improve their evaluation score from the scenario without assistant system is increased more than installing Day2 system.
- The more mixing rate of AD vehicles are increase (20% -> 30%), so that the effective for improving merging becomes high, then the more the number of AD vehicles that improve their evaluation score,

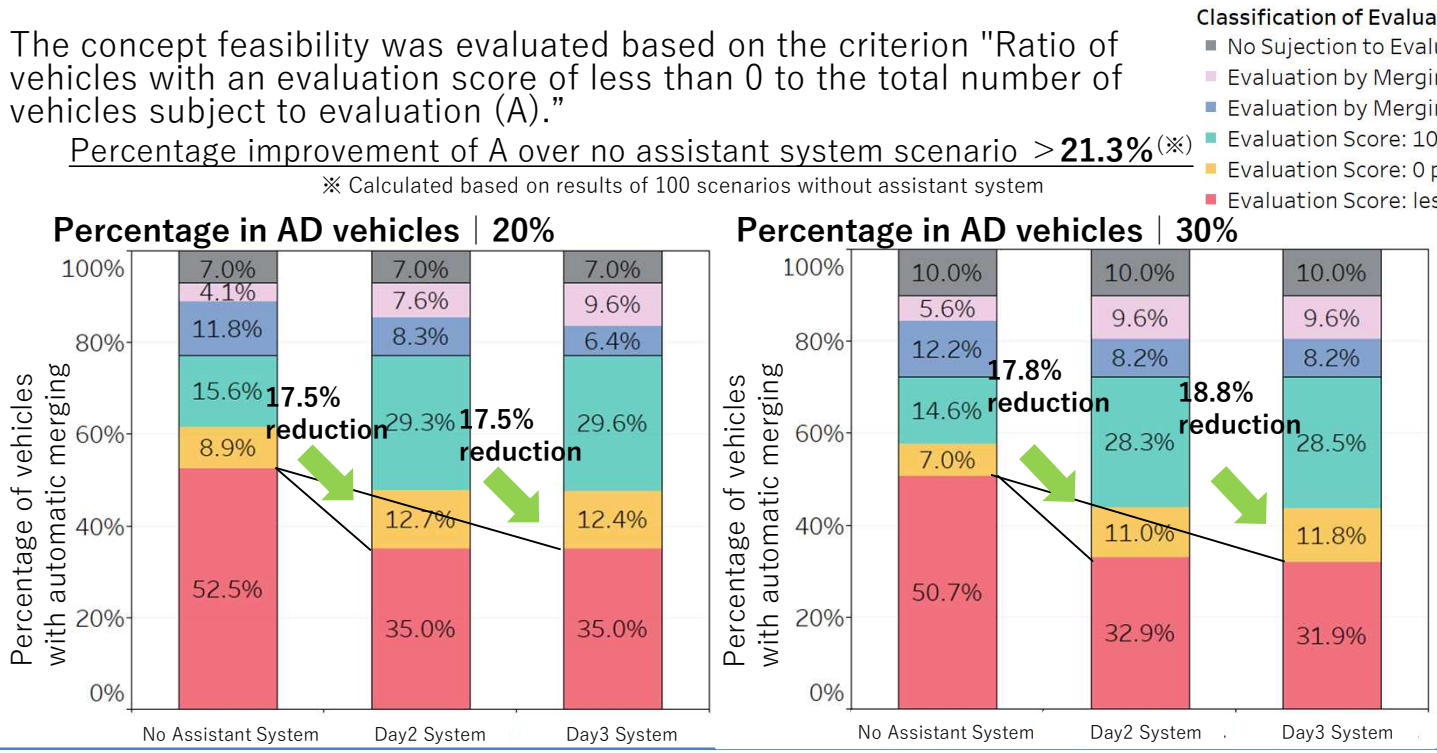
-> **To installing the Day3 system to the situation without assistant system, the high effect of improvement of merging same as Day2 system can be acquired.** However, it is limited that the effect of improvement of merging with adding "assistance for main lane AD vehicles to coordinate" by upgrading from Day2 to Day3.

4-2. Verification of the Feasibility of the Day3 System Concept Conceptual Feasibility

- The concept feasibility was evaluated based on the criterion "Ratio of vehicles with an evaluation score of less than 0 to the total number of vehicles subject to evaluation (A)."

  Percentage improvement of A over no assistant system scenario ＞**21.3%**(※)

  ※ Calculated based on results of 100 scenarios without assistant system



Evaluation Point	Merging Evaluation Score	Merging Forgo Evaluation
Compare with no assistant system	20%: Percentage of “Merging without enough space” decreased by 17.5% (improvement rate 33.3%) 30%: Percentage of “Merging without enough space” decreased by 18.8% (improvement rate 37.1%)	Almost no impact
Compared with the Day2 system	No impact	Almost no impact

The merging is no longer evaluated as "Merging without enough space"

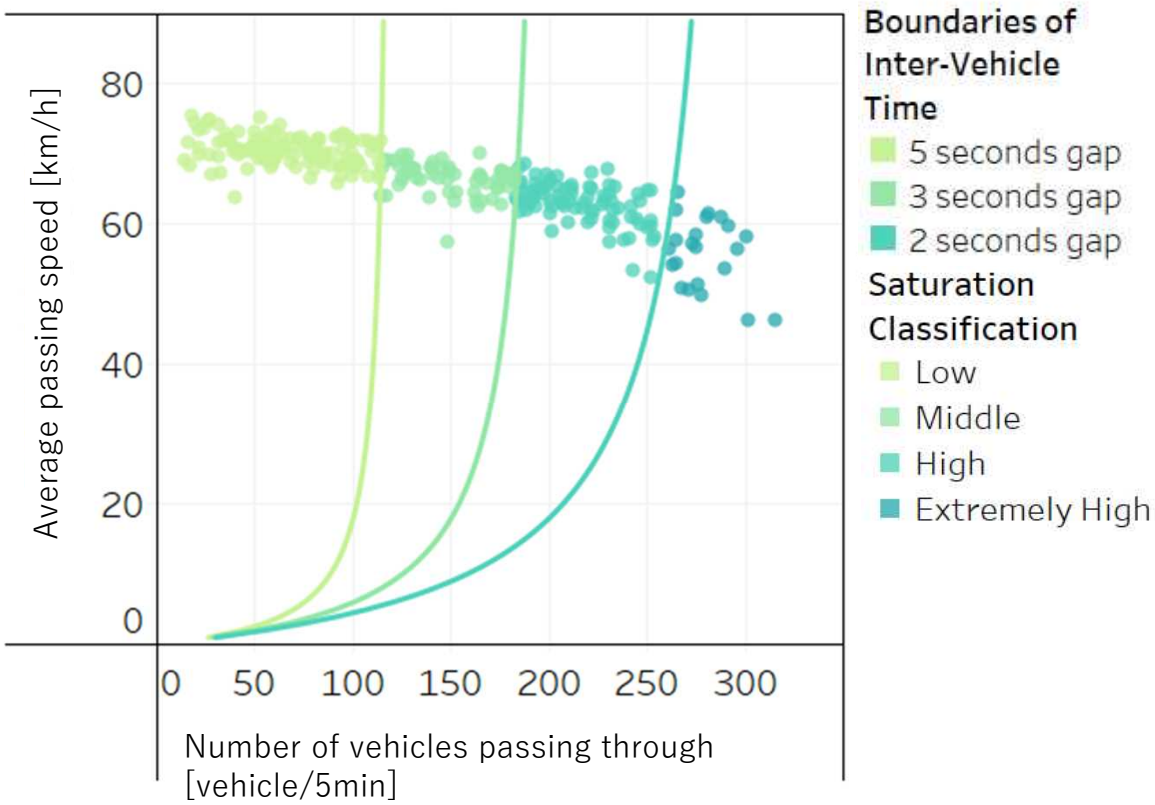
As same as the previous page, the number of AD vehicles that is no longer evaluated as "Merging without enough space" is increased more than installing Day2 system, however it is limited that the effect of improvement of merging with adding "assistance for main lane AD vehicles to coordinate" by upgrading from Day2 to Day3.

-> Be care that this conclusion is under the setting of the distance between vehicles with assistance is set at 2.5 seconds, so additional verifications under more diverse conditions are required.

5. Estimation of Daily Improvement Effect for Merging assuming Actual Traffic Flow

5. Estimation of Daily Improvement Effect for Merging Assuming Actual Traffic Flow

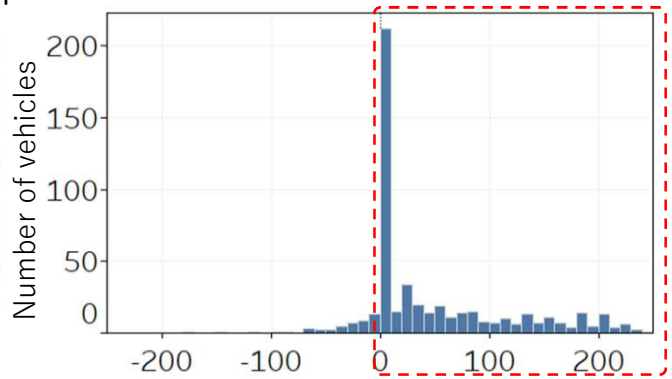
- Estimated effect of Day 2 and Day 3 systems on daily merging improvement.
- Estimation Method
  - Results of Day 2 system implementation scenario and Day 3 system implementation scenario compared to no assistant system scenario.
    - Mixing rate of AD vehicles: 20%.
    - Used traffic flow：Realistic traffic flow at the Higashi-Ikebukuro Entrance for one day
      Reproduce time-series changes in traffic flow in 5-minute increments.



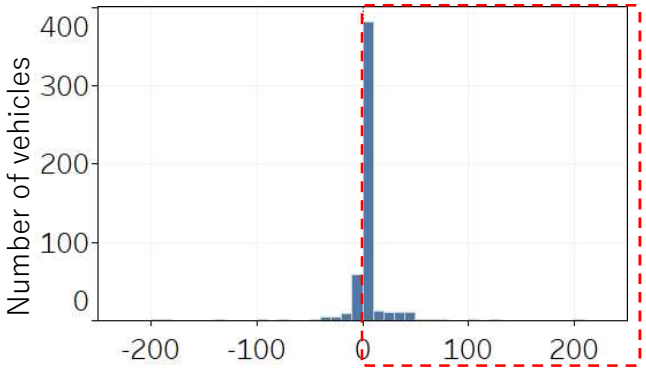
5. Estimation of Daily Improvement Effect for Merging Assuming Actual Traffic Flow Improvement Effect for Merging

- The effect of the merging improvement was evaluated by the distribution of the change in evaluation points associated with the installation of the Day 2 and Day 3 systems.

Percentage in merging AD vehicles

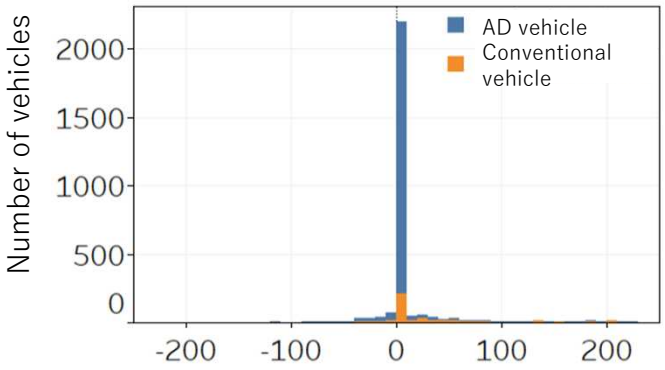


Amount of change in evaluation points associated with the installation of the Day 2 system

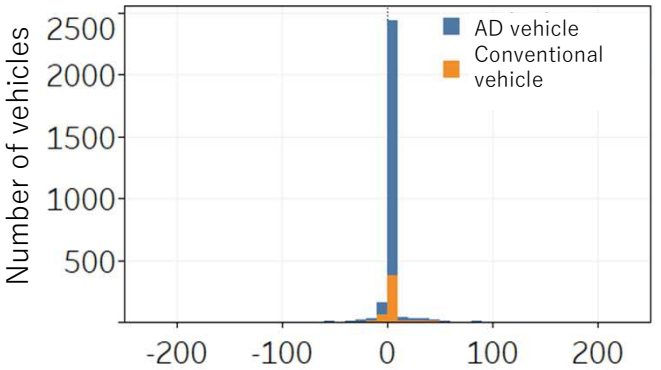


Amount of change in evaluation points associated with the change from the Day 2 system to the Day 3 system

Percentage in all merging vehicles



Amount of change in evaluation points associated with the installation of the Day 2 system



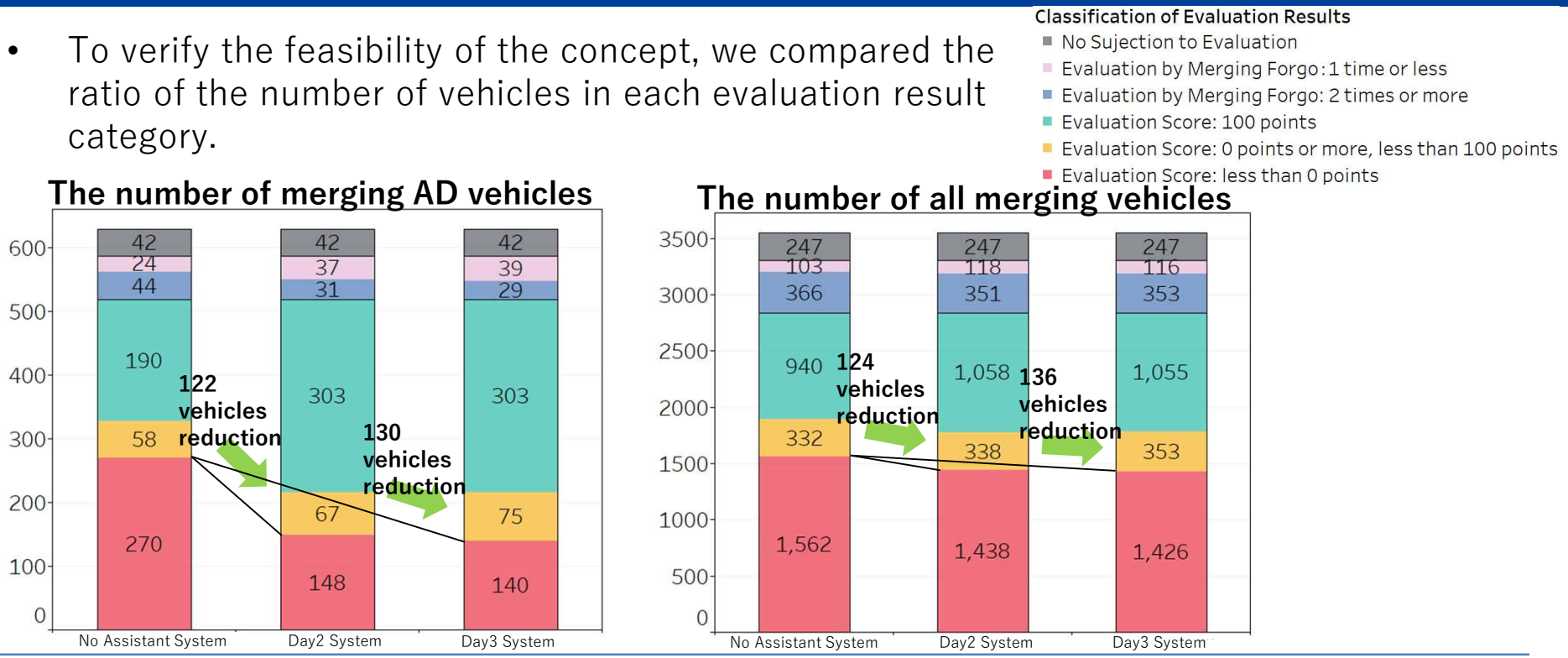
Amount of change in evaluation points associated with the change from the Day 2 system to the Day 3 system

The range of improvement in evaluation scores

AD merging vehicles: Improvement in evaluation points was observed with the installation of the Day 2 system.
Conventional merging vehicles: Most of them showed zero range of improvement in evaluation points.

5. Estimation of Daily Improvement Effect for Merging Assuming Actual Traffic Flow Conceptual Feasibility

- To verify the feasibility of the concept, we compared the ratio of the number of vehicles in each evaluation result category.



Evaluation Point	System	Merging Evaluation Score	Merging Forgo Evaluation
Only merging AD vehicles	Day2 system	“Merging without enough space” decreased (122vehicles)	Almost no impact
	Day3 system	“Merging without enough space” decreased (130vehicles)	Almost no impact
All merging vehicles	Day2 system	“Merging without enough space” decreased (124vehicles)	Almost no impact
	Day3 system	“Merging without enough space” decreased (136vehicles)	Almost no impact

The merging is no longer evaluated as "Merging without enough space"

Day2 and Day3 system have reduced the number of “Merging without enough space” about half.
If the effect of Day2 system against no assistant system is 100%, the effect of Day3 system was about 107%. There is a possibility of further improvement with a different setting.

6. Summary

6-1. Prerequisites and Implementation Details for this Project

- Main Preconditions
  - Target site: The Higashi Ikebukuro Entrance on the off-ramp of Ikebukuro Line of the Metropolitan Expressway No.5
  - Assumed AD vehicle diffusion range: 20% and 30% AD vehicle mix
    - Assumed relatively early stage of AD vehicle diffusion: 20% and 30% AD vehicle mixing rate
  - Basic behavior of AD vehicles and behavior change by the merging assistant system
    - Basic behavior of AD vehicles: Assumed to have a larger gap between vehicles than the average of general drivers, and to keep more than 2 seconds between vehicles in front of them.
    - Day2 system: **Adjusts speed and spacing for merging lane AD vehicles by pre-adjusting acceleration/deceleration before they enter the merge area.**
    - Day3 system: In addition to the Day2 system, **AD vehicles on the main lane also perform pre-merge acceleration/deceleration before entering the merge area, to increase the time between vehicles in front of them.**
- Details of Implementation
  - Day2 system Verification
    - Verification of the Feasibility of the Day2 System Concept
    - Verification of the Effect of Merging Improvement When System Physical Conditions are Changed
    - Verification of the Effect of Merging Improvement When Traffic Flow Conditions are Changed
  - Feasibility of the Day3 System Concept
    - Verification of the Feasibility of the Day3 System Concept
  - Evaluation method
    - Evaluation from two perspectives: "Improvement Effect for Merging" and "Conceptual Feasibility" based on "evaluation points," which are calculated by scoring the margin between vehicles in front and behind the merging vehicle based on the gap distance between vehicles and relative speed.
    - Improvement Effect for Merging: Evaluation of the amount of improvement in each vehicle's evaluation points compared to the situation without the assistant system.
    - Conceptual Feasibility: Judged based on the amount of improvement of "Merging without enough space*1" relative to the state without the assistant system, as follows
      1. Calculate the scenario without the assistant system 100 times and estimate the probabilistic fluctuation of the simulation (variation in the amount of merging without enough space).
      2. Determine the effectiveness of the Day2 system by determining whether or not the "amount of merging without enough space" improved beyond probabilistic fluctuation*2 when the Day 2 system was installed.

*1 Merging without enough space : A merging that requires strong deceleration of 0.3 G or more when reducing the relative speed to 0 km/h while keeping a gap distance of 15m or more between the vehicles in front of the merging vehicle and the merging vehicle and between the merging vehicle and the vehicle behind the merging vehicle after merging.
*2 "Improvement rate > 18.6%" was used as the threshold value. The threshold is defined as "improvement rate of no margin merging = 1 - amount of margin without enough space in the scenario with the assistant system / amount of margin without enough space in the scenario without the assistant system." The threshold value(18.6%) was calculated by adapting the box-and-whisker outlier determination algorithm to the results of 100 occurrences of the no assistant system scenario.

6-2. Validation Conditions and Results of the Day2 System

Day2 system: Adjusts speed and spacing for merging lane AD vehicles by pre-adjusting acceleration/deceleration before they enter the merge area.

- Verification conditions
  - Assumed AD vehicle diffusion range: 20% AD vehicle mix
    - Assumed relatively early stage of AD vehicle diffusion: 20% AD vehicle mixing rate
  - System physical condition items:
    - Location Error, Monitoring / Communication Area, Transmission Time of Information, Speed Information Error
  - Traffic flow condition: Simulated traffic volume in actual traffic flow at the target location
  - Patterns for changing traffic flow conditions: The following four patterns based on average vehicle duration
    - Saturation low (>5 sec), Saturation medium (5 sec-3 sec), Saturation high (3 sec-2 sec), Saturation extra high (<2 sec)

<table>
<tr><th>Subject</th><th>Verification details</th><th>Verification results</th></tr>
<tr><td rowspan="3">Day2 System</td><td>Verification of the Feasibility of the Day2 System Concept</td><td>• Most of the AD vehicles that merged showed an improvement in evaluation points, confirming the effectiveness of the Day2 system in improving merging. (P.25)
• The installation of the Day 2 system approximately halved the amount of "Merging without enough space," confirming the effectiveness of the concept. (P.26)</td></tr>
<tr><td>Verification of the Effect of Merging Improvement When System Physical Conditions are Changed</td><td>• The validity of the concept was confirmed within the range of favorable system physical conditions (see table below). (P.29)
<table>
<tr><th>Monitoring Area</th><th>Communication Area</th><th>Transmission Time of Information</th><th>Speed Information Error</th><th>Location Error</th></tr>
<tr><td>80m or more</td><td>130m or more</td><td>0.8s or less</td><td>±6km/h</td><td>None</td></tr>
</table></td></tr>
<tr><td>Verification of the Effect of Merging Improvement When Traffic Flow Conditions are Changed</td><td>• The validity of the concept was confirmed to be maintained within the low to high saturation range (P.31)
• Especially in the low saturation level, the effect was so high that "Merging without enough space" with low evaluation score was suppressed to about 5% of merging AD vehicles.</td></tr>
</table>

6-3. Validation Conditions and Results of the Day3 System

Day3 system: In addition to the Day2 system, AD vehicles on the main lane also perform pre-merge acceleration/deceleration before entering the merge area, to increase the time between vehicles in front of them.

- Verification conditions
  - Assumed AD vehicle diffusion range: 20% and 30% AD vehicle mix
    - The AD vehicle mixing rate of 30% was verified based on the assumption that the AD vehicle penetration rate is 30% or higher, which is assumed as the timing for the introduction of Day 3. In addition, the AD vehicle mixing rate of 20% was also verified to confirm the effect of system improvement from Day 2 to Day 3.
  - Inter-vehicle time expansion target: Acceleration/deceleration in advance so that the main lane AD vehicle **expands the gap time between vehicles in front of it 2.5 seconds or more**.
  - Traffic flow conditions: Traffic volume (high saturation) that reduces the effect of the Day 2 system's merging improvements.

Subject	Verification details	Verification results
Day3 System	Verification of the Feasibility of the Day3 System Concept	• **Verification of Day 3 under limited conditions confirmed the same level of merging improvement effect and "Merging without enough space" as the Day 2 system when installed in a situation without assistance.** (**P.37,38**) →However, this analysis did not cover all the conditions that make up Day 3. To confirm the effectiveness of the Day 3 system, further studies are needed to expand the effectiveness of the Day 3 system by conducting additional verification under more diverse conditions.

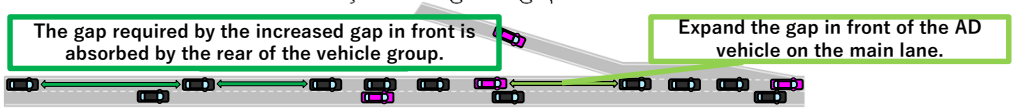
6-4. Points Requiring Further Study and Effectiveness Verification

- Two suggested directions for future verification are as follows
- Verification of the effectiveness of the merge assistant system under a wider range of conditions
  - It is desirable to verify the effectiveness of the merge assistant system under a wider variety of verification conditions to accumulate more robust findings.
    - Examples of verification conditions are listed in the table on the right.
- Examination of functional specifications of the merge assistant system
  - For example, the following issues identified in this study could be considered

Condition Items	Example of Conditions
Mixture of AD vehicles	under 20%、over 30%、etc.
Car model	Trucks, motorcycles considered
System Physical Conditions	The closer to the vehicle detection sensor, the smaller the error, etc.
Road alignment	Another Metropolitan Expressway
Basic behavior of AD vehicles	keep other than 2seconds between vehicle in front of them, etc.
Merge evaluation criteria	Parameter update of the evaluation point map
Effectiveness criteria	Update threshold calculation method
Simulation conditions for Day3 system	Analysis with changes in system physical conditions and saturation as in Day 2

Examples of points to consider for functional specification of a merge assistant system

Identified Issues	Points Requiring Consideration
Response to the case where vehicles are still on the main lane and there is no gap between vehicles to merge with enough space near the merging area.	**Consideration of ways to make adjustments in a planned rather than sequential manner.** • Need to expand the options between main lane vehicles that can be reached when merging, and to upgrade the main lane vehicle gap aiming assistant.
In the Day 3 system, the effect of increasing the gap between vehicles by 2 to 2.5 seconds was limited.	**To study methods of expanding the gap between main lane vehicles and examine their effectiveness and side effects.** • Widening the gaps between vehicles may prolong the vehicle convoys below 40 km/h for a long period of time. • It is necessary to consider how to increase the gap between vehicles that can merge by utilizing the gap between vehicles on the main lane upstream of the merge area.



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