Professional Design & Engineering Firm

# FY2021 Annual Report

# The Second Phase of Cross-Ministerial Strategic Innovation Promotion Program / Automated Driving for Universal Services / Simulation Analysis of Verification of Merge Support System

May 2022

KOZO KEIKAKU ENGINEERING Inc.

# Table of Contents

# Outline of Research



- Aiming at smooth merging on expressways, studies of the support systems, which provide vehicles with information, are ongoing
- The Day2 system provides merging vehicles with information about vehicles on the main line continuously
- The goal of this project is to confirm the feasibility of the Day2 system based on traffic simulations
- Specifically, we investigated necessary conditions of roadside-to-vehicle communication for the Day2 system, and summarized the effectivities of the Day2 system and acceptable errors of hardware including sensors

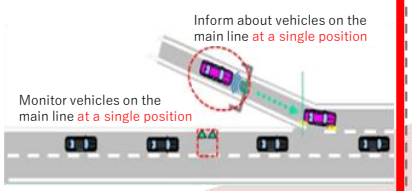
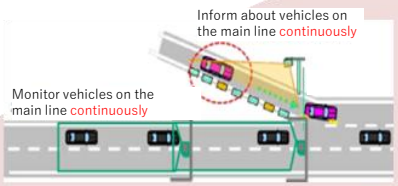
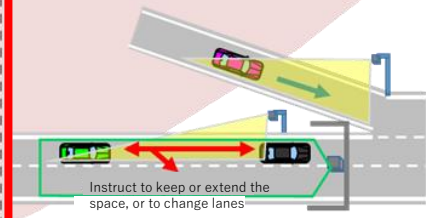
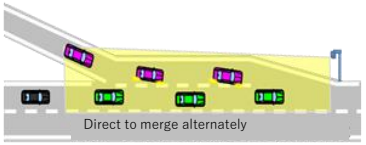
# Scope of the Project in the Roadmap



## The Roadmap of Merging Support Systems

JAMA

Scope of this project

| Day1 | Day2 | Day3 | Day4 |
|---|---|---|---|
| **Support preliminary acceleration and deceleration of vehicles on the merging lane** | **Support acceleration and deceleration of vehicles on the merging lane pointing to space between vehicles on the main line** | **Support to make space between vehicles on the main line** | **Support merging in traffic jams** |
| Monitor traffic speed and density of the main line, and inform in advance | Inform speed and location of vehicles on the main line continuously in addition to the Day1 support | Instruct vehicles on the main line to support merging in addition to the Day2 support | Negotiation among vehicles in traffic jams in addition to the Day3 support |
| **Spot monitoring and forecasting** | **Areal monitoring and continuous forecasting** | **Instructions by the road infrastructures** | **Negotiation by inter-vehicle communication** |
|  |  |  |  |
| Vehicles on the merging line accelerate to the traffic speed on the main line if the traffic on the main line is not dense | Vehicles on the merging line adjust speed not to run side-by-side with vehicles on the main line | Vehicles on the merging line adjust speed not to run side-by-side with vehicles on the main line<br>Vehicles on the main line keep/extend the space or change lanes | Automated merging in traffic jams |

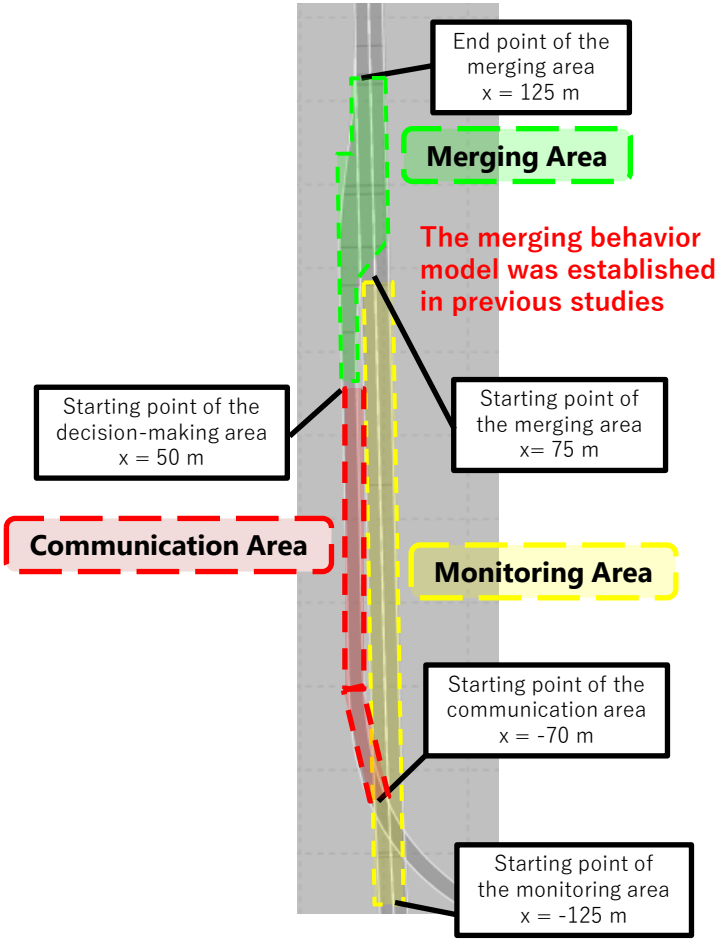
# 2. Simulation Overview

# Simulation Overview

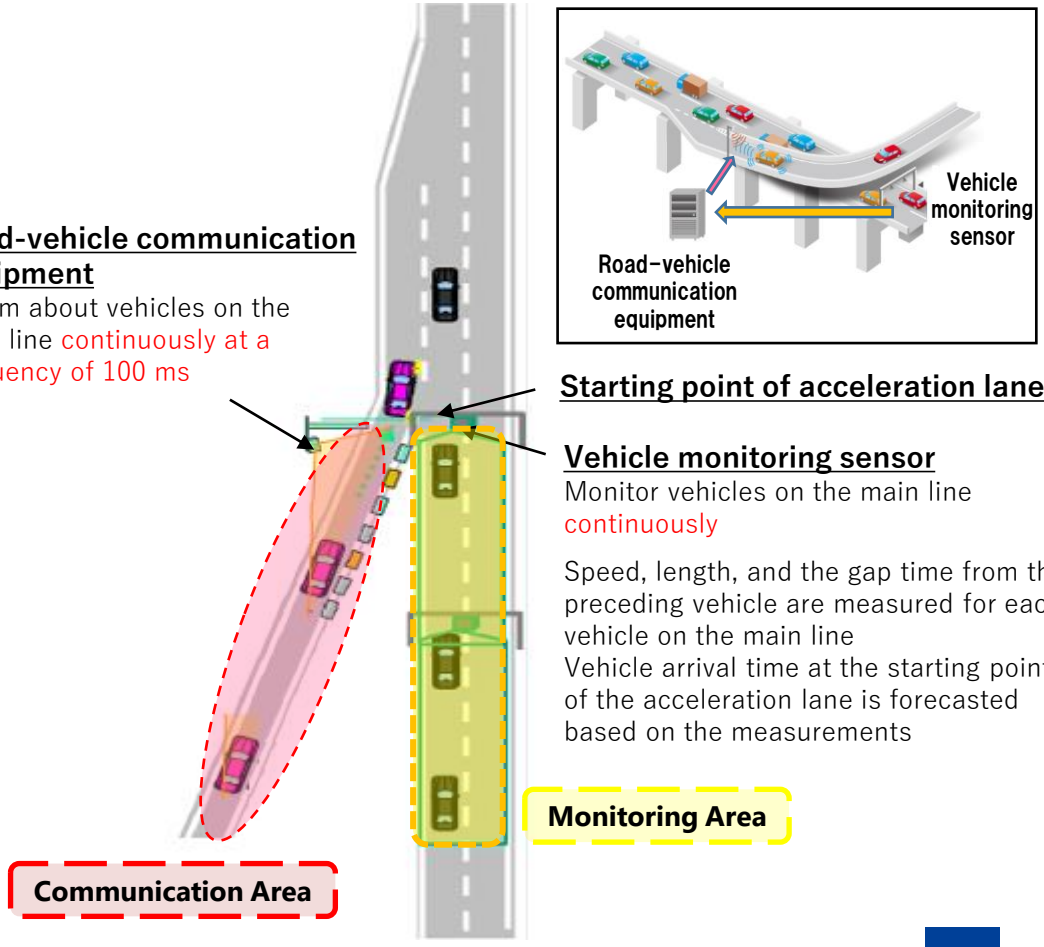
Innovating for a Wise Future
構造計画研究所
KOZO KEIKAKU ENGINEERING Inc.

To evaluate the effectiveness of the Day2 system, the simulation environment was established to simulate the merging situation with the Day2 system

## Road alignment at the target site




## The Day2 system concept

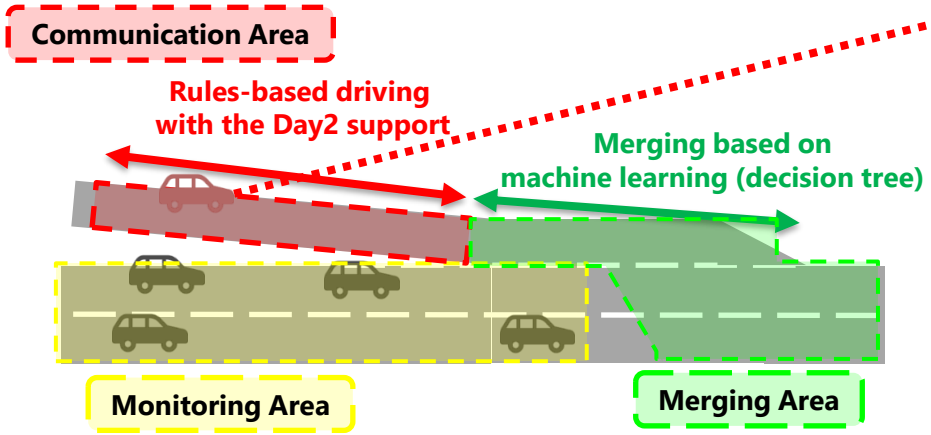


# Driving Behavior in the Simulation



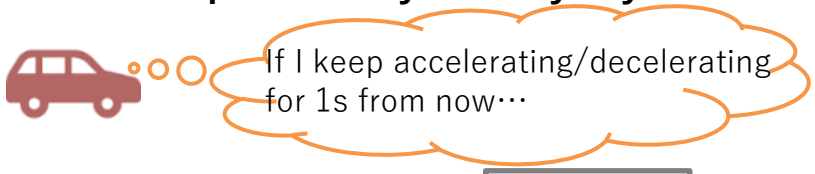
The driving behavior of a merging vehicle (automated vehicle) supported by the Day2 system is defined as follows

**Provide information to merging vehicles by the Day2 system**




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

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




| | |
|---|---|
| (1) Strong acceleration +0.2G | Score: -30 |
| (2) Weak acceleration +0.1G | Score: 50 |
| (3) Keep current speed +0.0G | Score: 80 |
| (4) Weak deceleration -0.1G | Score: 100 |
| (5) Strong deceleration -0.2G | Score: 70 |

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

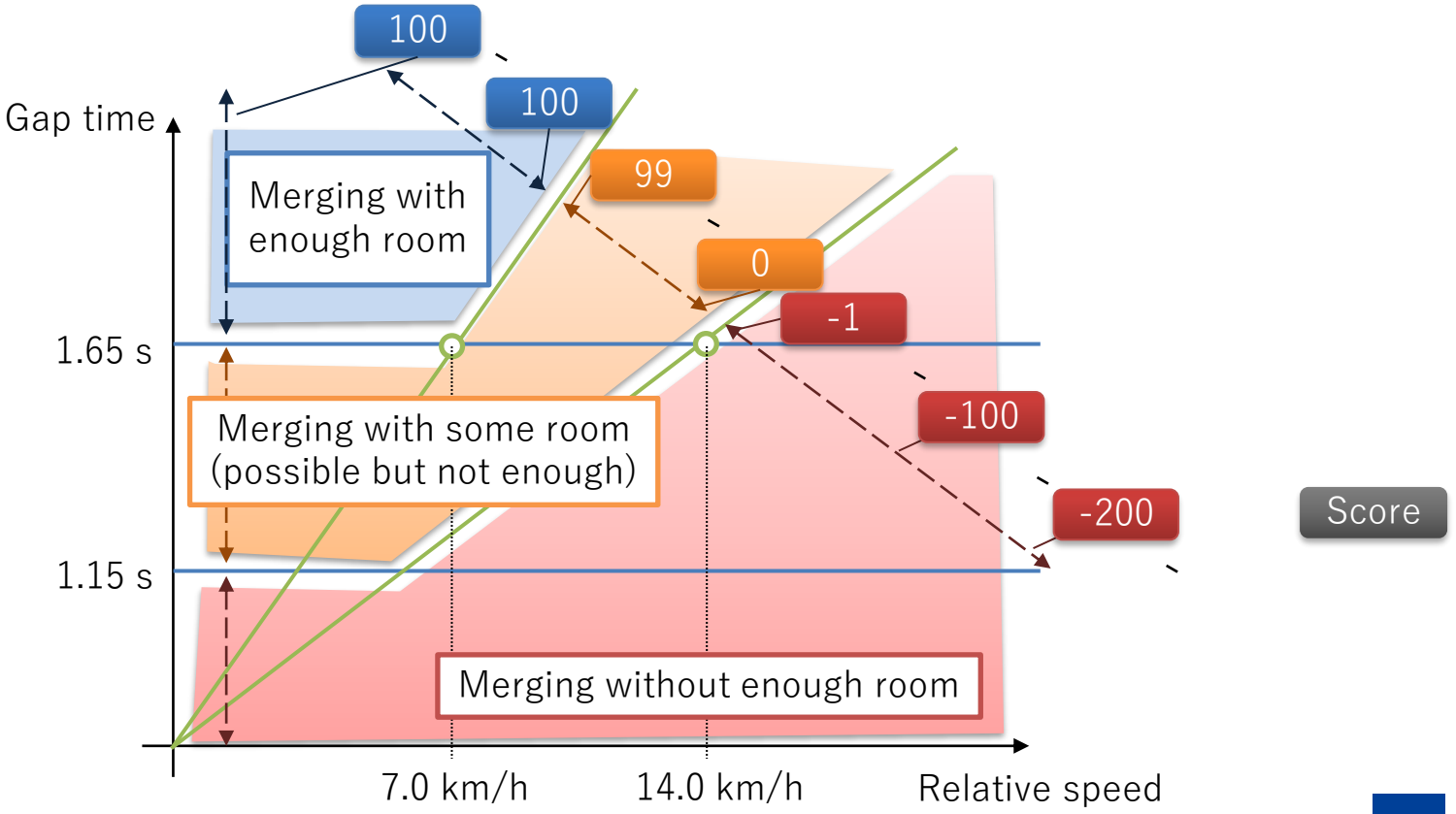
*Vehicle speeds are set based on actual driving data, and thus may not obey legal speed limits

# Indicator of Merging Goodness



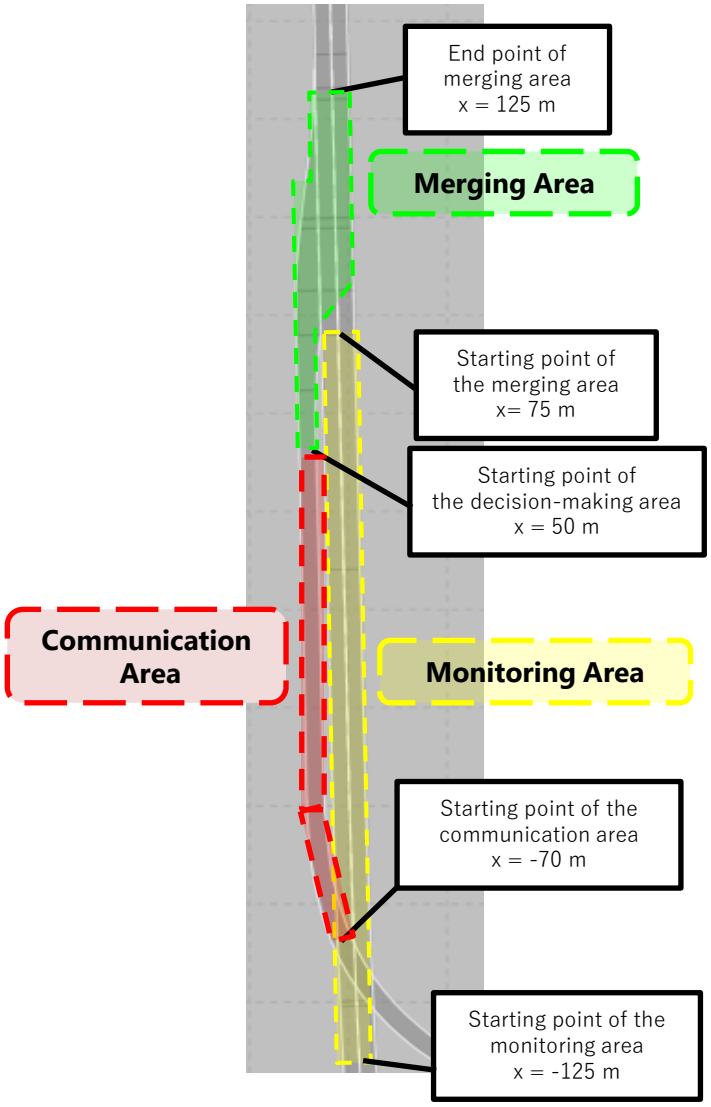
"Evaluation Score" was defined as an indicator of merging goodness

- Defined based on gap time and relative speed to vehicles on main line, considering safety and traffic efficiency
- The score increases up to 100 as the vehicle merges with enough room
- Merging with negative score is defined as merging without enough room



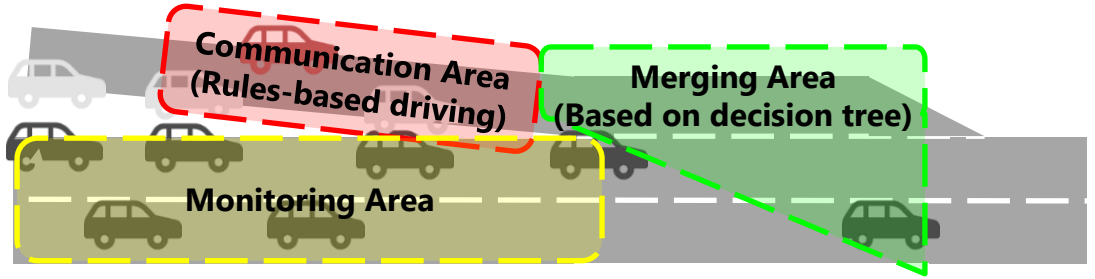
# Simulation Parameters






## The Day2 system conditions can be modified by using following parameters

| Categories | Items | Example values |
|---|---|---|
| Traffic conditions | Automated vehicle mixing rate | 0%, 20%, 30%<br>*Automated vehicles are generated only on the merging lane |
| The Day2 system conditions | Availability of the Day2 support | With or without the Day2 support |
| | Monitoring area length | 200 m, 180 m, 160 m, 140 m<br>(Upstream from the starting point of the merging area) |
| | Communication area length | 120 m, 100 m, 80 m, 60 m, 40 m<br>(Upstream from the starting point of the merging area) |
| | Information delivery delay | Mean: 0 s, 0.4 s, 0.8 s, 1.3 s<br>Standard deviation: 0 s, 0.2s |
| | Information error | Position: • Without error • The uniform distribution of ±1 m |
| | | Speed: • Without error • Gaussian distribution of -12 ~ +12 km/h at maximum |



# Settings on the Day2 System conditions



- Evaluation of the Day2 system effectiveness
  - Evaluated the Day2 system effectiveness **under the ideal Day2 system conditions**

- Evaluation of acceptable conditions for the Day2 system
  - Evaluated the effects on the support effectiveness **by changing the Day2 system conditions**

# 3. Evaluation of the Day2 System Effectiveness

# Outline



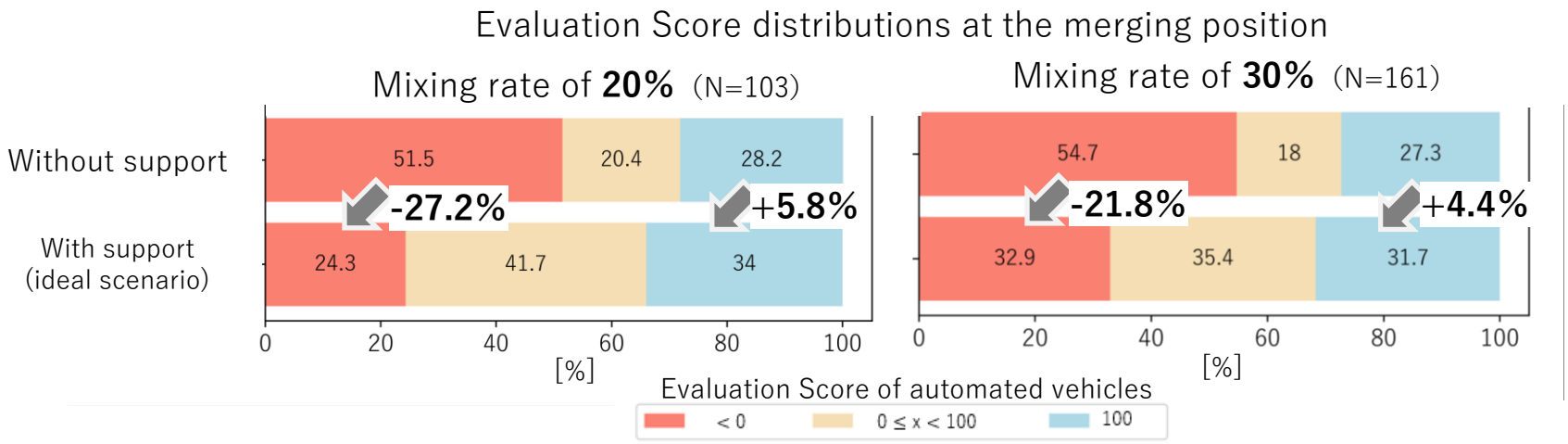
- The Day2 system effectiveness was evaluated under the ideal Day2 system conditions
  - “Ideal scenario” conditions
    - Monitoring area length of 200 m
    - Communication area length of 120 m
    - Without information delay nor error
  - Automated vehicle mixing rate: 20% or 30%

- Contents
  1. Analysis of the merging improvement impacts
  2. Factor analysis of merging unimproved with the support
  3. Analysis of influences on surrounding traffic flow

# Merging Improvement Impacts



- The Evaluation Score distributions were compared between scenarios with and without the Day2 support
  - The comparison was performed in the both situations in which automated vehicle mixing rates of 20% and 30%
- In the both situations, **merging was improved by the support**




| | Support effect on the merging vehicles | |
|---|---|---|
| | Mixing rate of 20% | Mixing rate of 30% |
| Merging without enough room (Evaluation Score < 0) | Decrease by 27.2% | Decrease by 21.8% |
| Merging with enough room (Evaluation Score = 100) | Increase by 5.8% | Increase by 4.4% |

# Factor Analysis of Merging Unimproved with the Support (Factor Classification)



- **Even in the ideal scenario with the support, 25 automated vehicles (24.3%) merged without enough room (negative Evaluation Score)** at the automated vehicle mixing rate of 20%
- For each case, the cause of the unimprovement was investigated by analyzing the time series data of the simulation output
- As a result, causes were classified as following
  (Details are in following slides)
  - A. Dense traffic on the main line: 14 cases
  - B. Merging behavior model (decision tree): 4 cases
  - C. Evaluation Score definition: 7 cases

**Breakdown of the causes of the merging without enough room (25 cases in total)**

| A. Dense traffic on the main line 14 cases | B. Merging behavior model 4 cases | C. Evaluation Score 7 cases |
|---|---|---|

# Factor Analysis of Merging Unimproved with the Support (Cause A. Example)

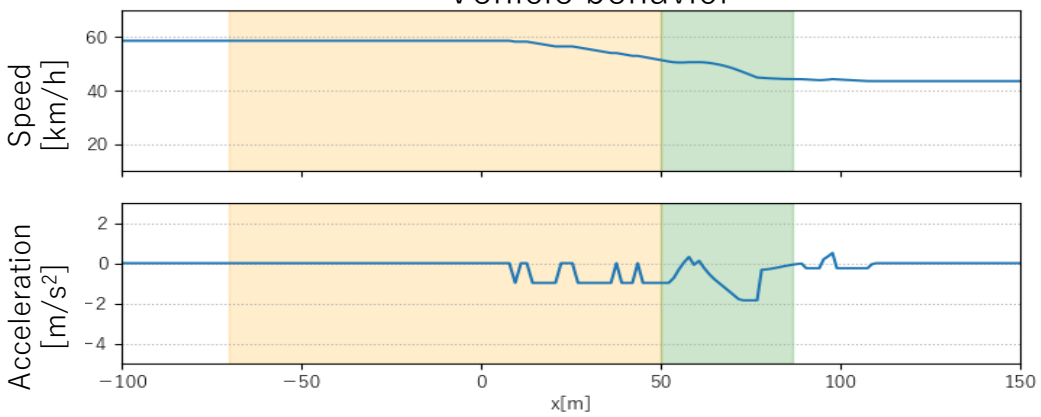
Innovating for a Wise Future
構造計画研究所
KOZO KEIKAKU ENGINEERING Inc.

A. Dense traffic on the main line

Evaluation Score: -150.8, Average distance between vehicles: 27.8 m

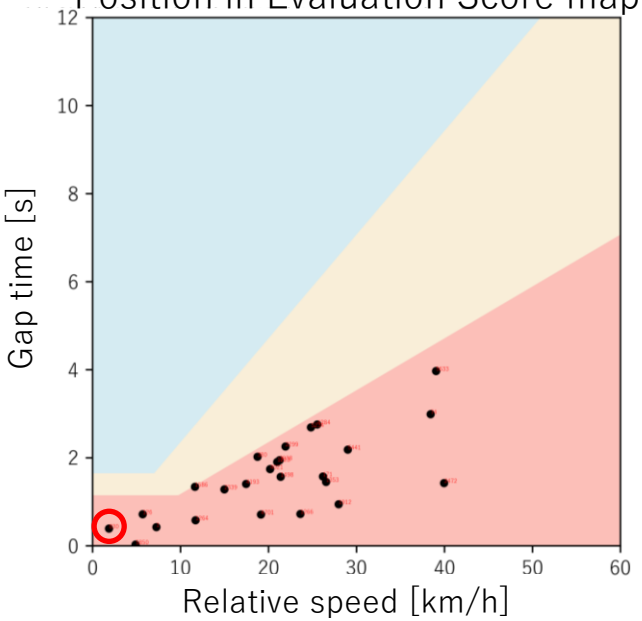
- Dense traffic on the main line caused the merging into a narrow space
- **Successful support by the Day2 system is difficult in such a situation, and the merging can be improved in the Day3 system**

Vehicle behavior




Situation at the merging

Position in Evaluation Score map



# Factor Analysis of Merging Unimproved with the Support (Cause B. Example)

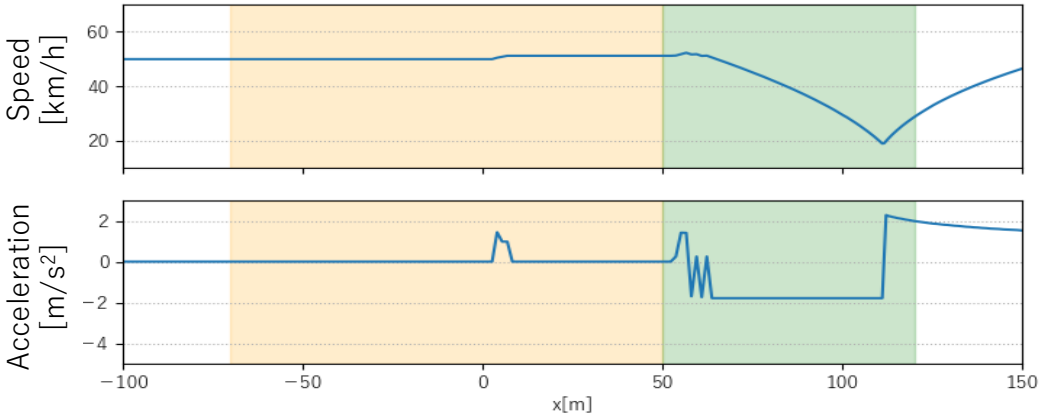


B. Merging behavior model (decision tree)

Evaluation Score : -69.6, Average distance between vehicles: 99.5 m

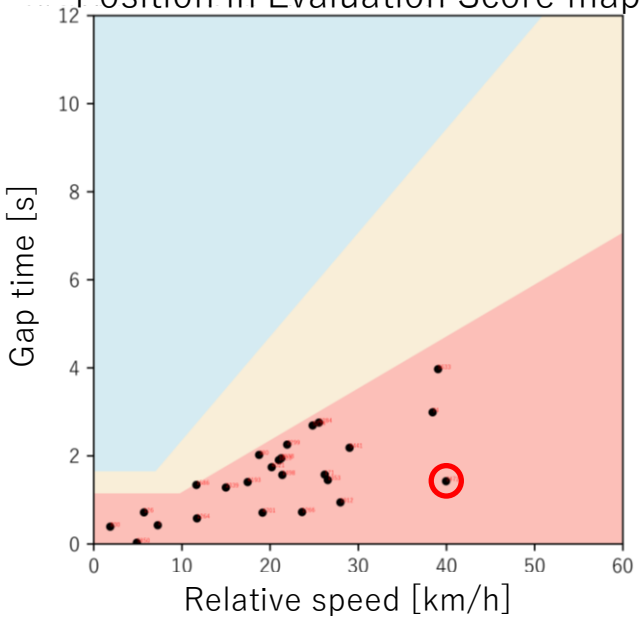
- Despite the enough space between vehicles, the decision tree selected to wait because merging probability was lower than the threshold
- **Since decision trees are constructed from a finite number of real data, there may be cases where a decision cannot be made properly**

Vehicle behavior




Situation at the merging
(The decision tree selected to wait in this situation)

Position in Evaluation Score map




https://www.kke.co.jp

# Factor Analysis of Merging Unimproved with the Support (Cause C. Example)

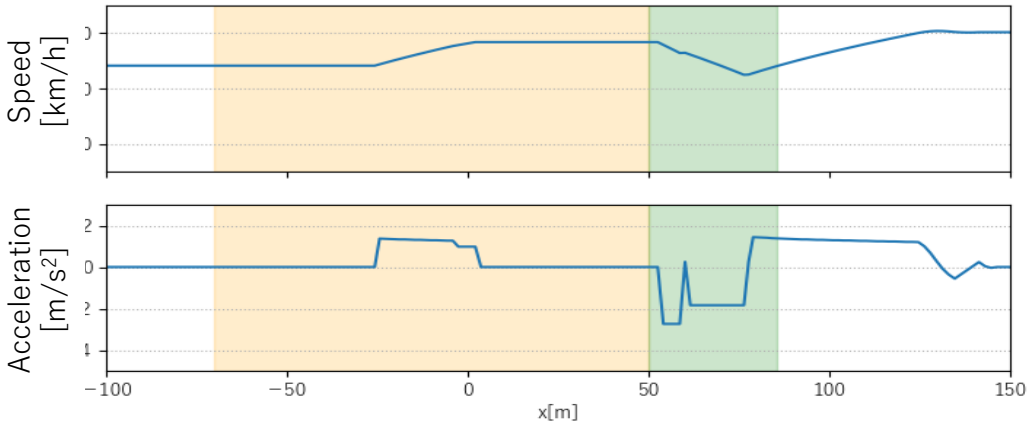


## C. Evaluation Score definition

Evaluation Score : -1.7, Average distance between vehicles: 65.9 m

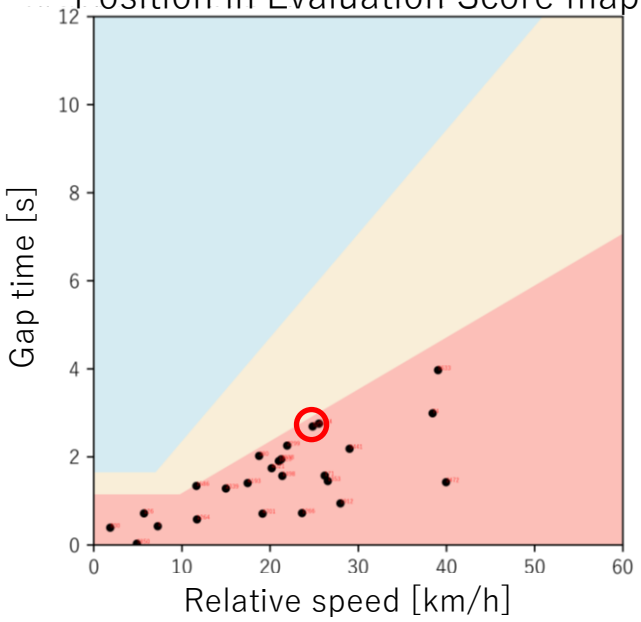
- Merging with enough space to the following vehicle after accelerating
- While the gap time was larger than 2s, Evaluation Score was negative because Evaluation Score decreases as the relative speed increase
- **Whether this example should be classified as a “merging without enough space” or not is controversial**

Vehicle behavior




Situation at the merging

Position in Evaluation Score map



# Summary of Factor Analysis of Merging Unimproved with the Support



- As a result of the time series data analysis, causes of the 25 merging cases without enough room even with the support were classified as following

**Breakdown of the causes of the merging without enough room (25 cases in total)**

| A. Dense traffic on the main line 14 cases | B. Merging behavior model 4 cases | C. Evaluation Score 7 cases |
|---|---|---|

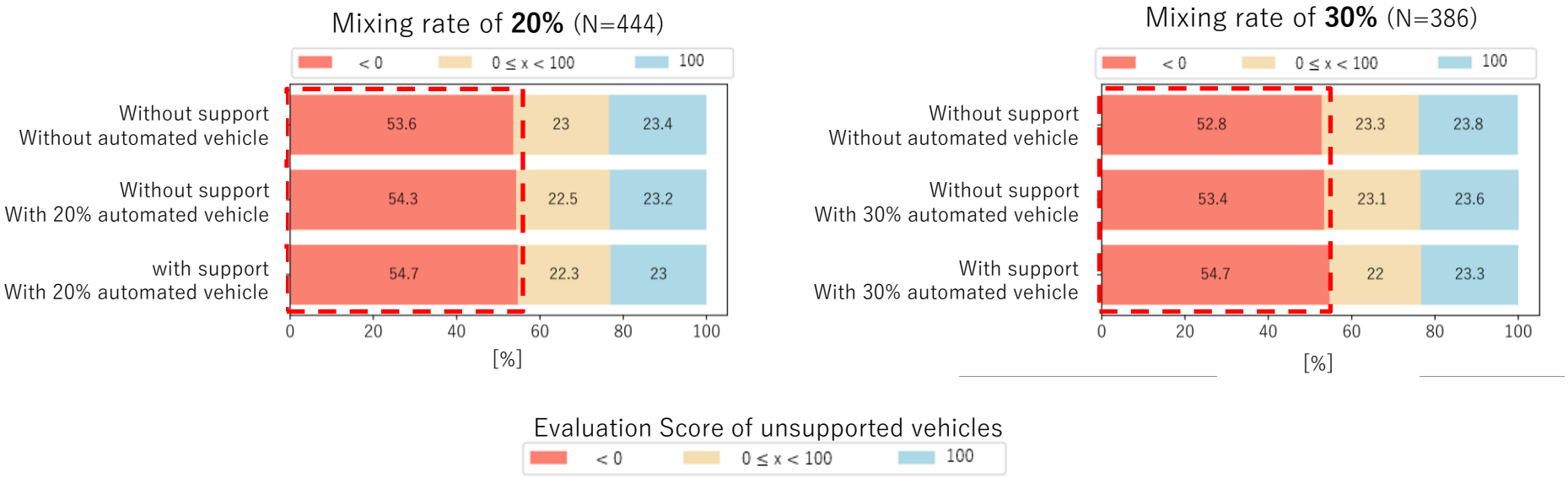
- Conclusion and Discussion
  - A little more than the half cases were due to dense traffic on the main line
    **Successful support by the Day2 system is difficult in such a situation, and the merging can be improved in the Day3 system** (Cause A.)
  - The remaining cases (fewer than the half) had issues with the merging behavior model or with the evaluation, thus **the evaluation of the Day2 support effectiveness may be underestimated by Evaluation Score** (Causes B. and C.)

# Influences on Surrounding Traffic Flow (Evaluation Score of Unsupported Vehicles)



- The distributions of Evaluation Score for unsupported vehicles were compared with and without the support under the automated vehicle mixing rate of 20% and 30%, respectively
- As a result, no significant change in the distribution of Evaluation Score was found, and thus **no influence on the merging of unsupported vehicles was observed**

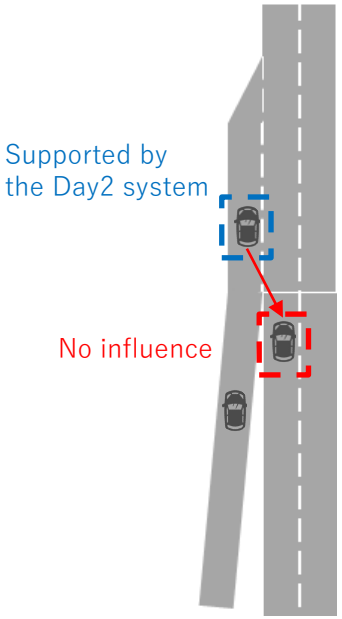
Distribution of Evaluation Score of unsupported vehicles

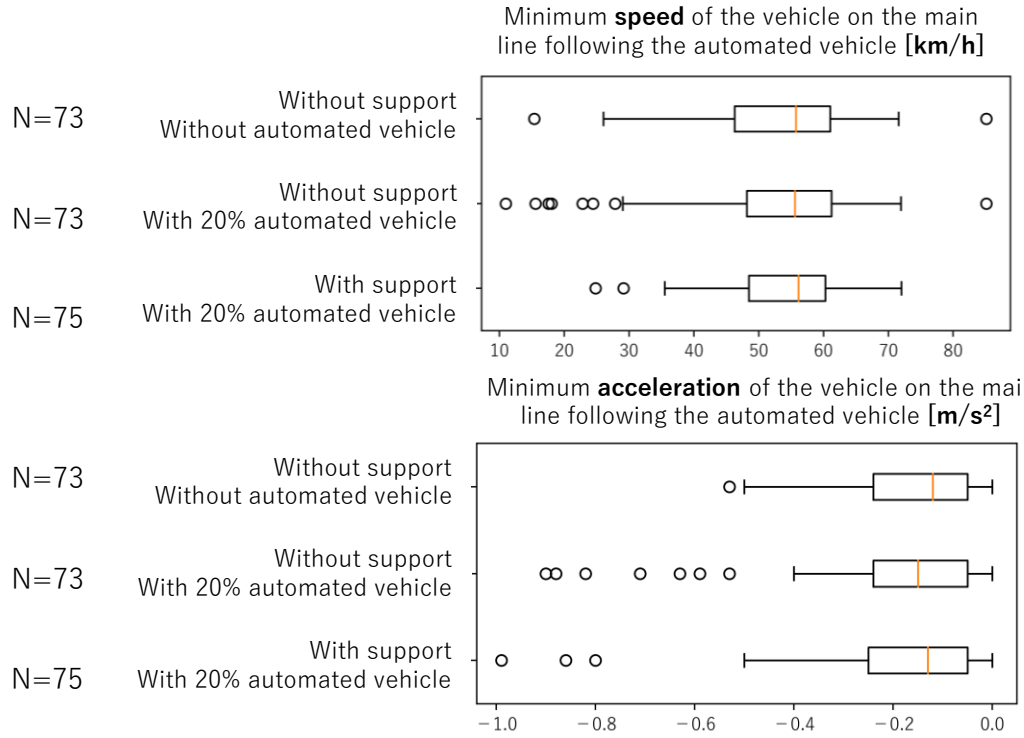


# Influences on Surrounding Traffic Flow (Following Vehicles on the Main Line)



- The distributions of the minimum speed and acceleration of the vehicles on the main line following the automated vehicle were compared with and without the support
- As a result, no significant change in the distributions was found, and thus **no influence on vehicles on the main line was observed**

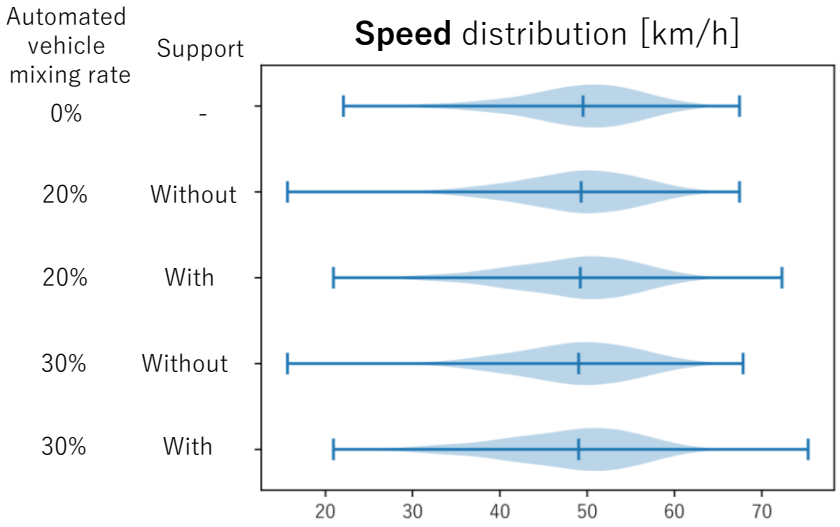


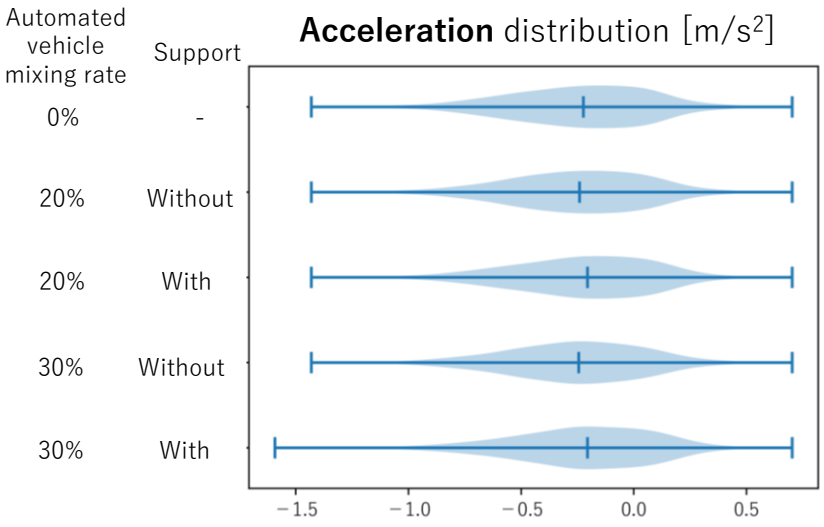



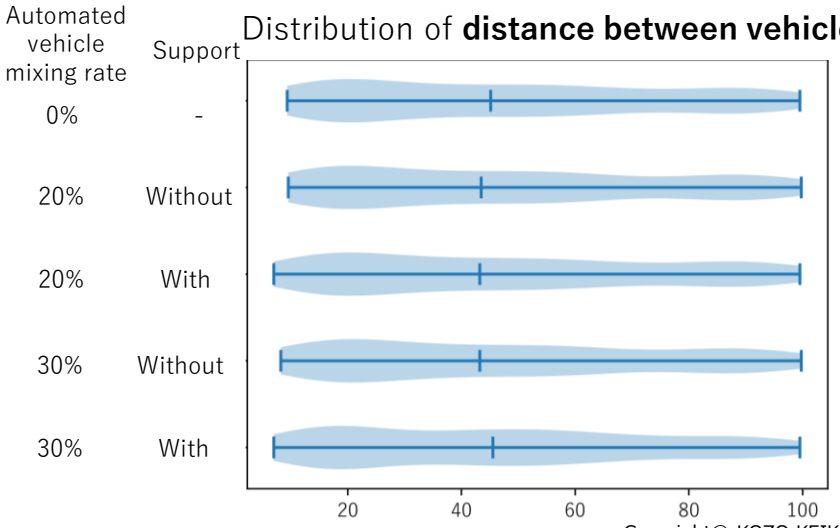
# Influences on Surrounding Traffic Flow (Merging Lane)

Innovating for a Wise Future
構造計画研究所
KOZO KEIKAKU ENGINEERING Inc.

No significant change was observed in the distributions of speed, acceleration, and distance between vehicles on the merging lane (N=547)



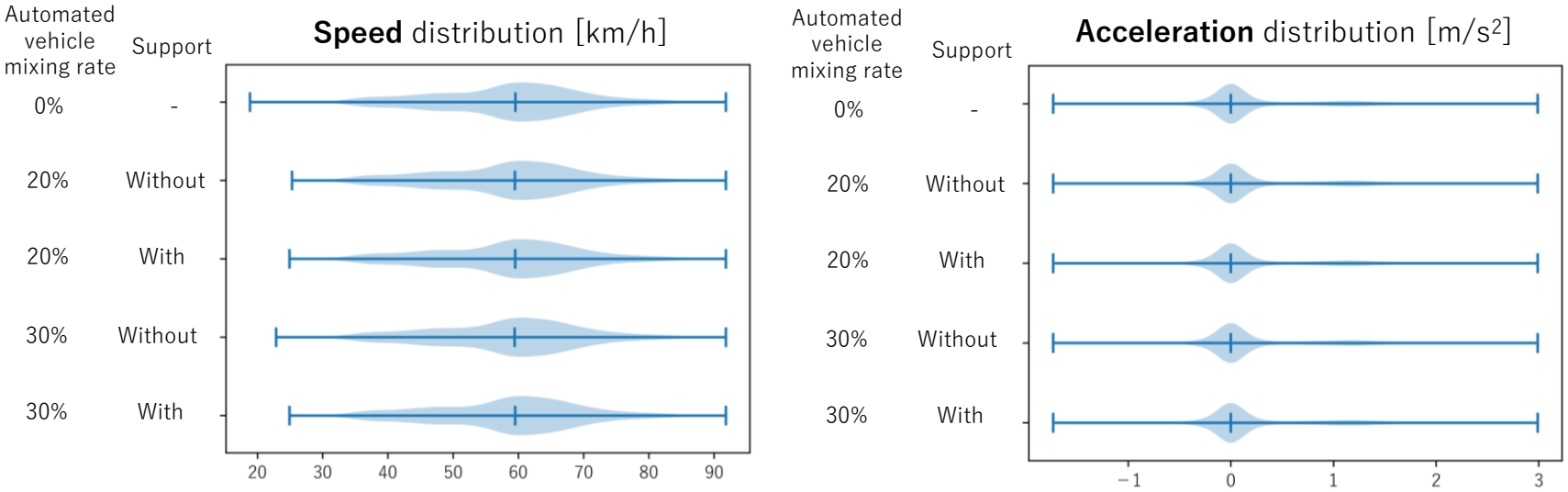



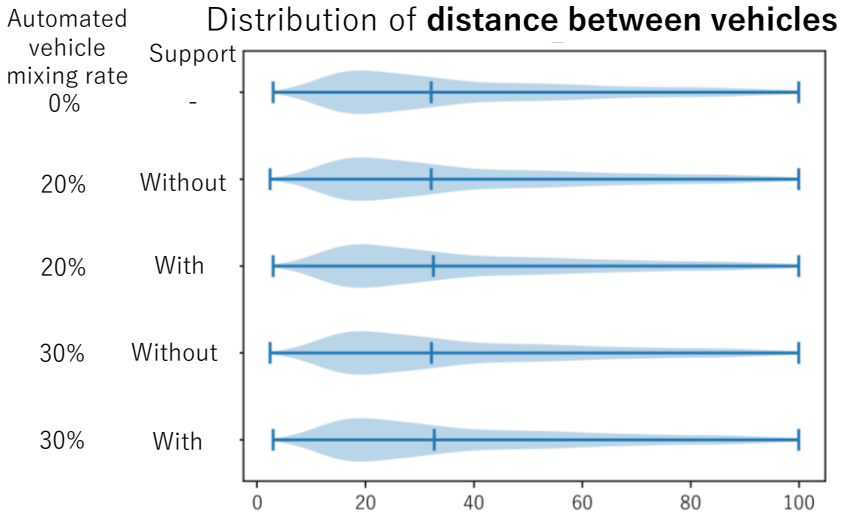



# Influences on Surrounding Traffic Flow (Main Line)

Innovating for a Wise Future
構造計画研究所
KOZO KEIKAKU ENGINEERING Inc.

No significant change was observed in the distributions of speed, acceleration, and distance between vehicles on the main line (N=3,177)

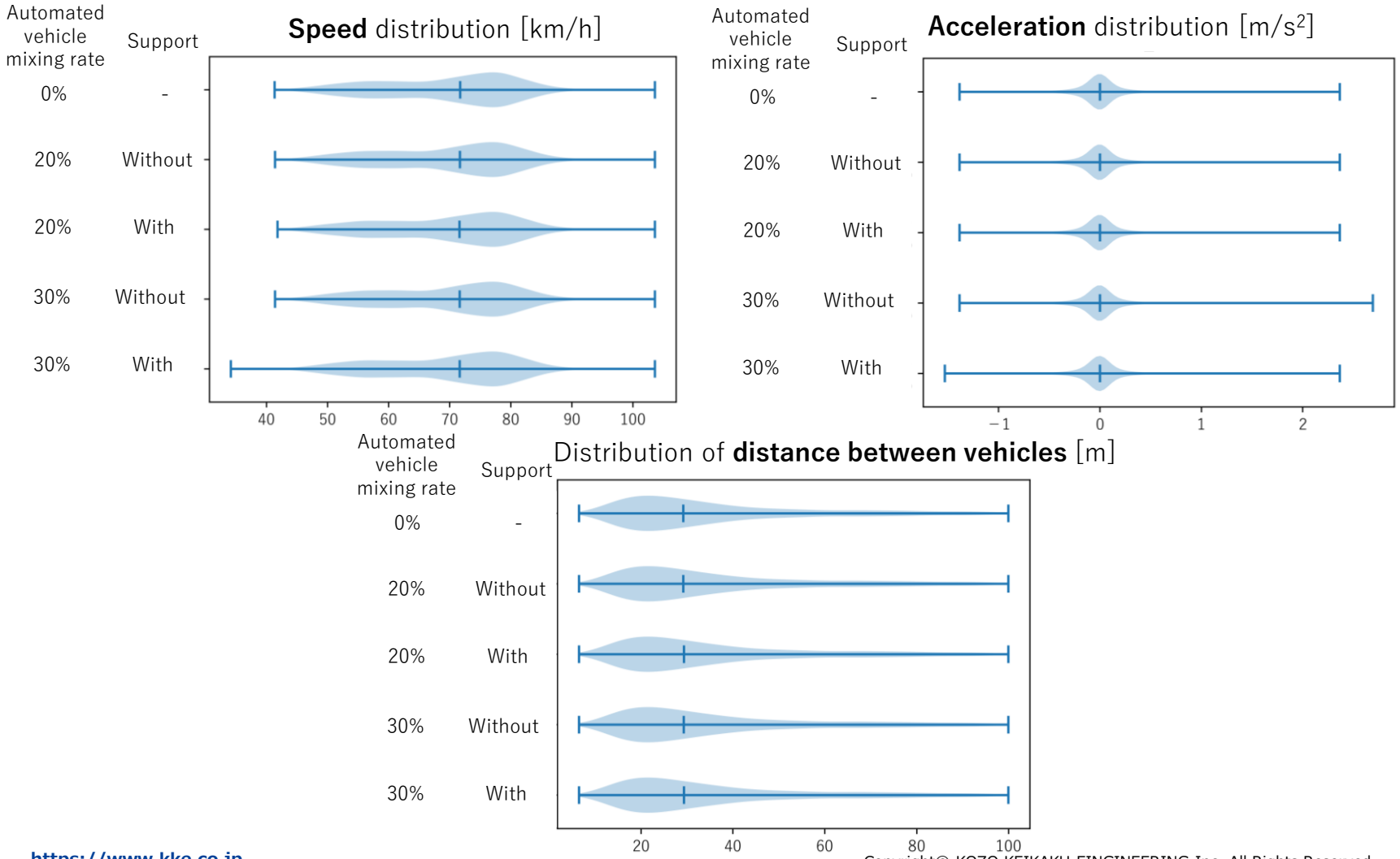


# Influences on Surrounding Traffic Flow (Overtaking Lane)

Innovating for a Wise Future
構造計画研究所
KOZO KEIKAKU ENGINEERING Inc.

No significant change was observed in the distributions of speed, acceleration, and distance between vehicles on the overtaking lane (N=4,091)



# Summary of Evaluation of the Day2 System Effectiveness



- The Day2 system **will improve safety and efficiency of merging**
  - The ratio of merging with enough room increased by around 5%
  - The ratio of merging without enough room decreased by around 27%

- The Day2 system tends to be less effective when the traffic on the main line is dense
  - **Merging in such a situation can be improved by the Day3 system**

- **No influence on surrounding traffic was observed**
  - Merging of unsupported vehicles
  - Following vehicles in the main line
  - Traffic flow on the merging lane, the main line, and on the overtaking lane

# 4. Evaluation of Acceptable Conditions for the Day2 System

# Outline



- The effects on the support effectiveness were evaluated by changing the Day2 system conditions
  - System conditions to be varied: monitoring area length, communication area length, information delay, and information error
  - Automated vehicle mixing rate was fixed at 20%

- Contents
  1. Individual analysis for each system condition
     - The impact on the effectiveness of the Day2 system was analyzed as each condition is varied individually
  2. Combination analysis of multiple system conditions
     - The impact on the effectiveness of the Day2 system was analyzed as multiple conditions are varied simultaneously

# 4.1 Individual Analysis for Each System Condition

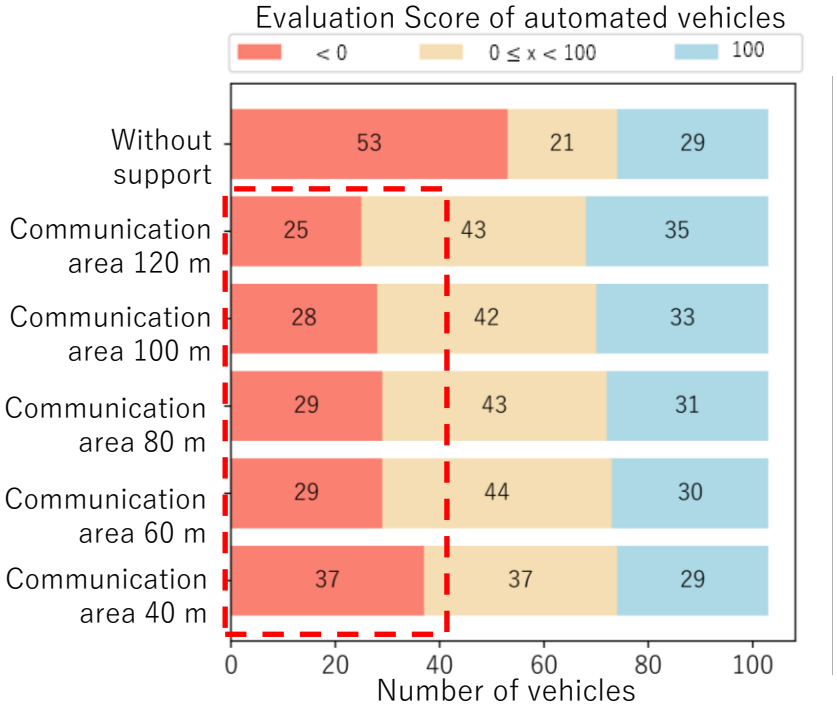
# Impact of Communication Area Length



- Scenarios
  - Communication area length: 120 m ~ 40 m
- As the communication area was shortened, **support effectiveness decreased** due to the increase of merging without enough room

**Communication area**
**As shortened, support effectiveness decreased due to the increase of merging without enough room**

Long
Short



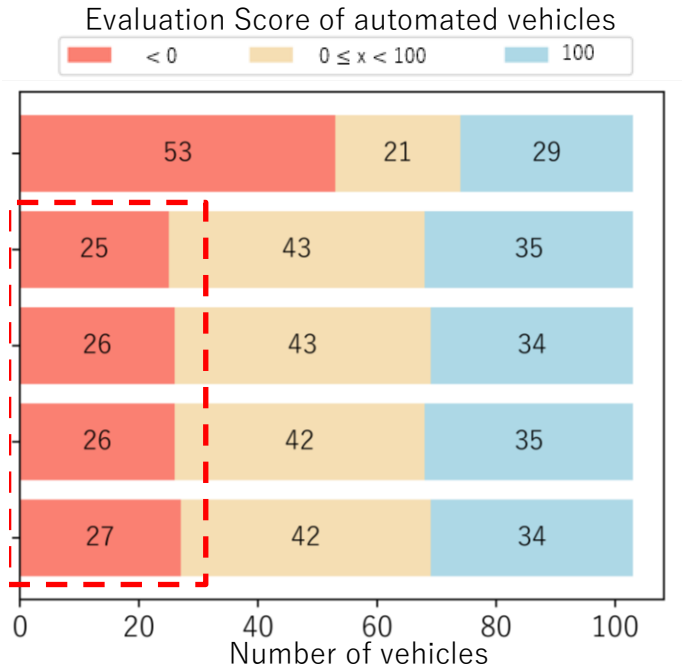
# Impact of Monitoring Area Length



- Scenarios
  - Monitoring area length: 200 m ~ 140 m
- No significant change in the Evaluation Score distributions was observed, resulting in **no effect of monitoring area length on the effectiveness of the support**

**Monitoring area**
**No effect on the effectiveness**

Long
Short

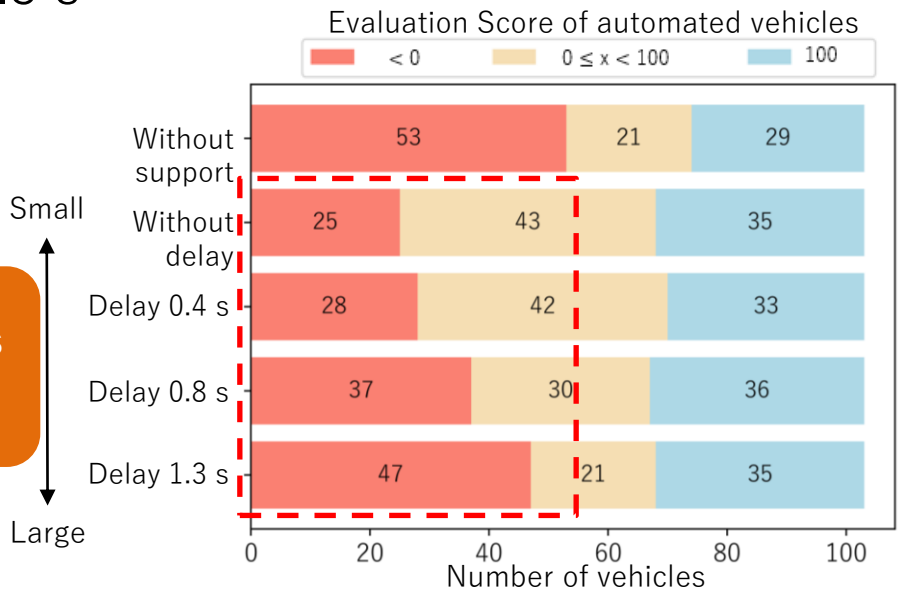


# Impact of Information Delay



- Scenarios
  - Information delay
    - Mean: 0 s ~ 1.3 s
    - Standard deviation: 0.2 s
- As the delay increased, **support effectiveness decreased** due to the increase of merging without enough room
  - The support effectiveness decreased greatly especially in the scenario with the delay of 1.3 s

**Information delay**
**As increased, the support effectiveness decreased due to the increase of merging without enough room**

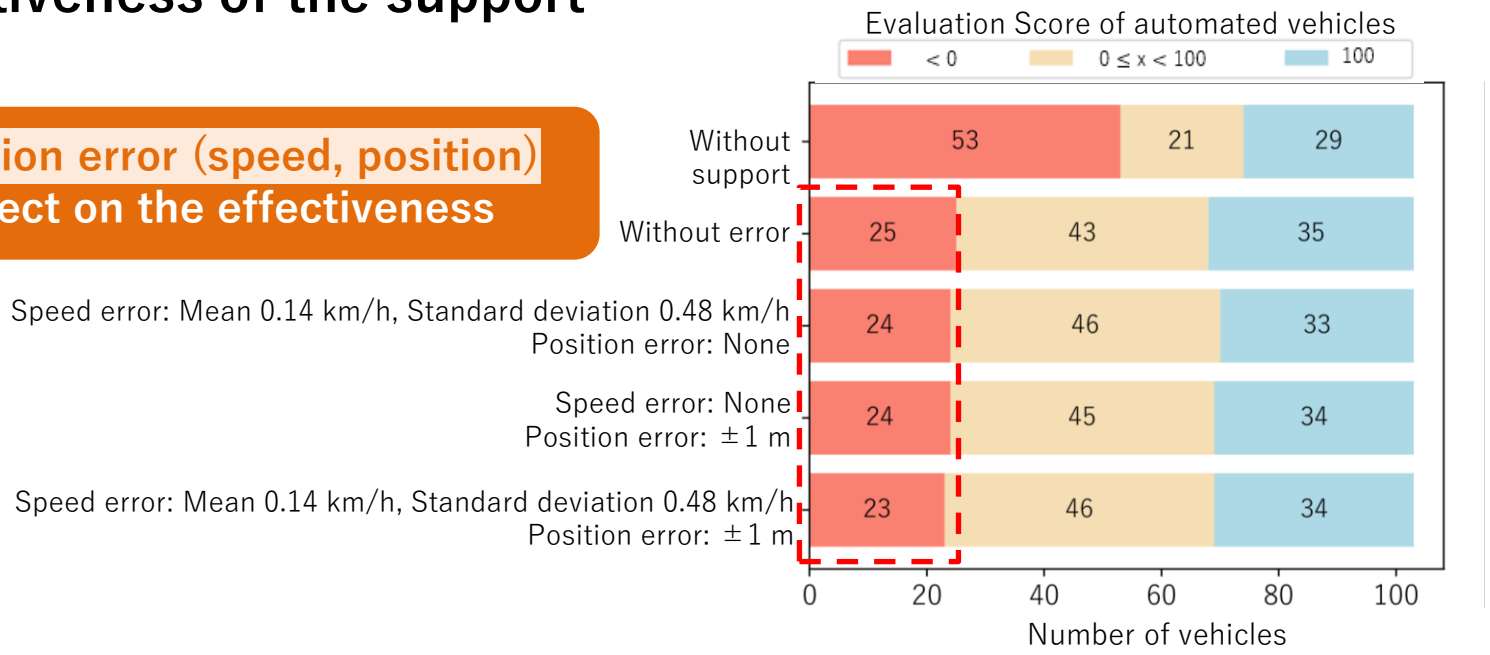


# Impact of Information Error



- Scenarios
  - Speed error: No error, or Gaussian distribution with the mean of 0.14 km/h and the standard deviation of 0.48 km/h
  - Position error: No error, or the uniform distribution of ±1m
- No significant change in the Evaluation Score distributions was observed, resulting in **no effect of speed and position error on the effectiveness of the support**

**Information error (speed, position)**
**No effect on the effectiveness**

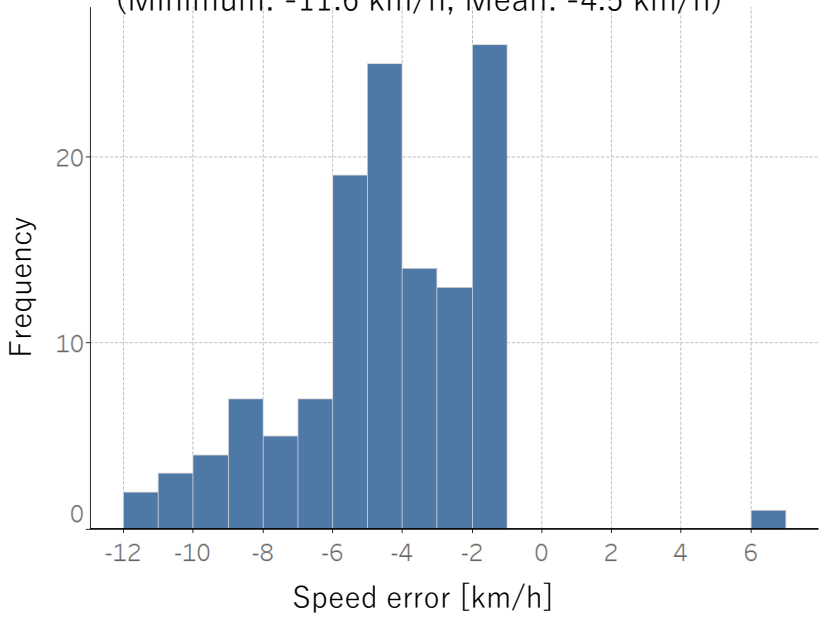


# Impact of Information Error (Modification of Speed Error Distribution)

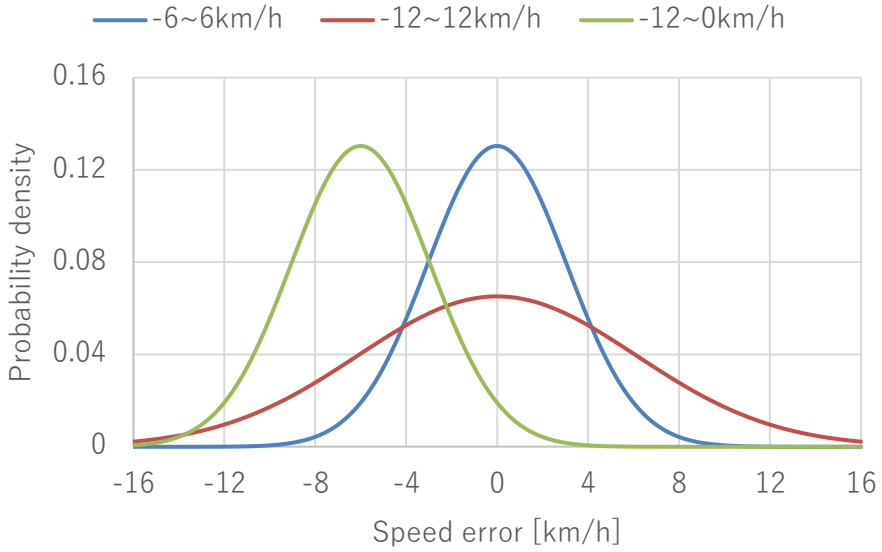


- The speed error is expected to be larger in the real system compared to the errors in the scenarios in the previous slide
- Scenarios with larger speed errors were added to the analysis
  - Based on experiment results, larger errors was assumed: Gaussian distribution with 95% confidence interval of -6 ~ +6 km/h, -12 ~ +12 km/h, and -12 ~ 0km/h
  - Position error of the uniform distribution of ±1 m was also considered

Speed error distributions measured by experiments on actual roads
(Minimum: -11.6 km/h, Mean: -4.5 km/h)



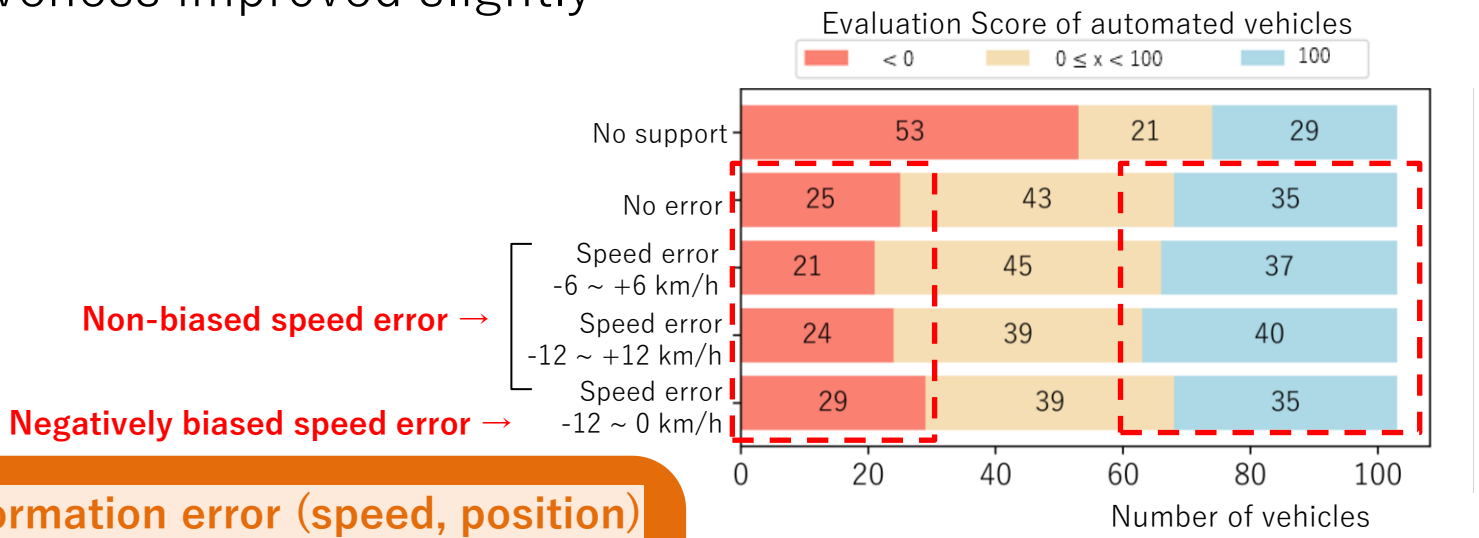

Speed error distribution given in scenarios



# Impact of Information Error (Result of Modification of Speed Error Distribution)



- **With the negatively biased speed error of -12 ~ 0 km/h, support effectiveness decreased** due to the increase of merging without enough room
- With the non-biased speed error, no significant change in the Evaluation Score distributions was observed, and the support effectiveness improved slightly




**Information error (speed, position)**
**The negatively biased distribution decreased the support effectiveness due to the increase of merging without enough room**

# Summary of Individual Analysis for Each System Condition



- **As the communication area was shortened, support effectiveness decreased**
  - Simulation was performed in the range of 120 m ~ 40 m upstream from the starting point of the merging area
  - The support effectiveness was not totally canceled out in this range
- **No effect of changes in the monitoring area length** on the effectiveness of the support was observed
  - Simulation was performed in the range of 200 m ~ 140 m upstream from the starting point of the merging area
- **As the information delay increased, support effectiveness decreased**
  - The support effectiveness was not almost canceled out at the delay of 1.3 s
- **No effect of position error on the effectiveness of the support** was observed
  - Simulation was performed with and without the uniform distribution of ±1 m
- **The speed error affected differently on the support effectiveness depending on the bias**
  - Error distribution without bias did not affect significantly on the effectiveness of the support
  - Negatively biased error distribution decreased the support effectiveness, but did not totally cancel out the effectiveness at the error of Gaussian distribution with 95% confidence interval of -12~0 km/h

# 4.2 Combination Analysis of Multiple System Conditions

# Outline



- The impact on the effectiveness of the Day2 system was analyzed with varying multiple conditions simultaneously

- Analysis targets
  - Combinations of area lengths and information delay
  - Combinations of area lengths and information errors
  - Combinations of information delay and errors
  - Combinations of area lengths, information delay, and errors

  *Area: monitoring area and communication area

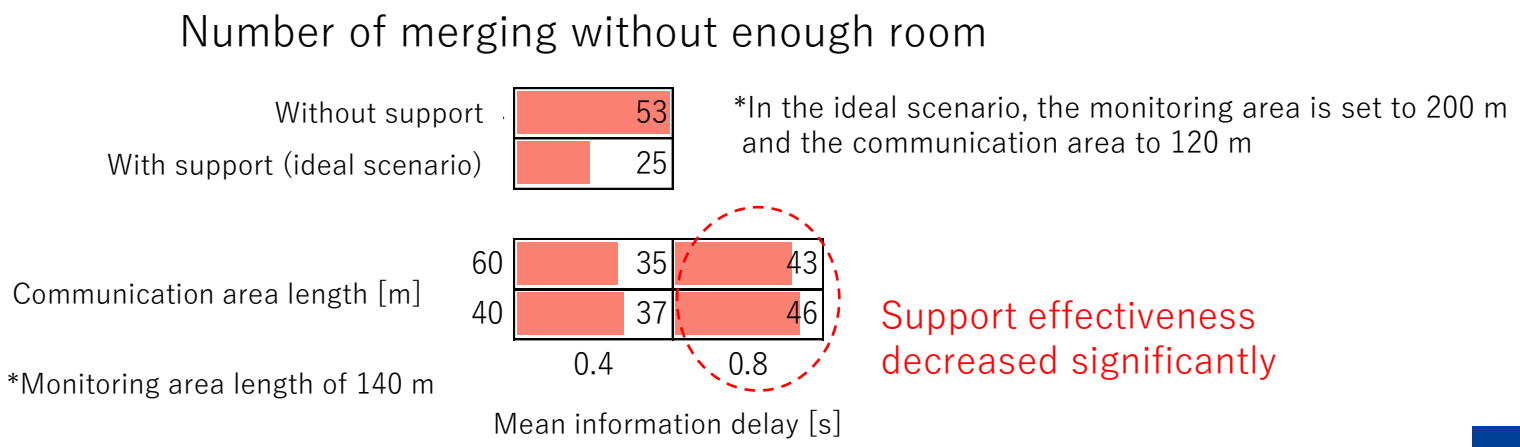
- The analysis focused on the number of merging without enough room (negative Evaluation Score)

# Combinations of Area Length and Information Delay



- 2 x 2 (4 in total) scenarios as following
  - (Monitoring area, Communication area): (140 m, 60 m) or (140 m, 40 m)
  - Delay: Mean of 0.4 s or 0.8 s (Standard deviation of 0.2 s)

  *The followings are considered simultaneously as minor errors:
    - Speed error with mean of 0.14 km/h, standard deviation of 0.48 km/h
    - Position error with the uniform distribution of ±1 m
- Results
  - **Evaluation Score decreased significantly compared to the scenarios with each condition varied individually**
  - The support effectiveness greatly decreased especially in the scenarios with the delay of 0.8 s



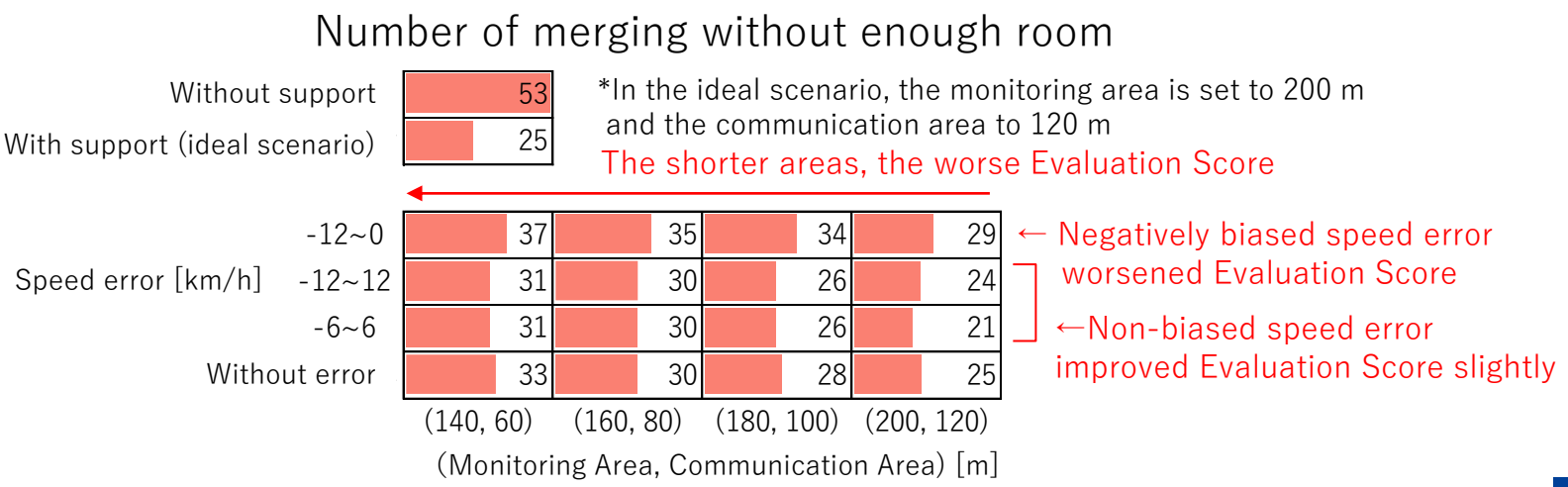
# Combination of Area Length and Information Error



- 4 x 3 (12 in total) scenarios as following
  - (Monitoring area, Communication area):
    (200 m, 120 m), (180 m, 100 m), (160 m, 80 m), or (140 m, 60 m)
  - Speed error: Gaussian distribution with 95% confidence interval of -6 ~ +6 km/h, -12 ~ +12 km/h, or -12 ~ 0km/h

  *Position error with the uniform distribution of ±1 m is considered simultaneously

- Results
  - **As the monitoring and communication areas were shortened, support effectiveness decreased**
  - With the negatively biased speed error, support effectiveness decreased slightly
  - With non-biased speed errors, support effectiveness improved slightly



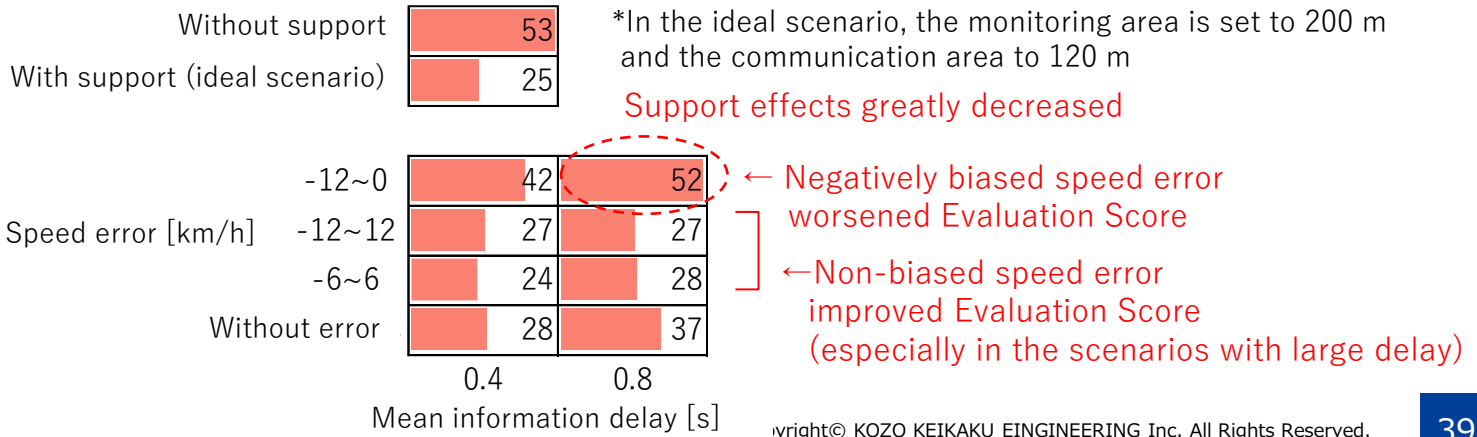
# Combination of Information Delay and Error



- 2 x 3 (6 in total) scenarios as following
  - Delay: Mean of 0.4 s or 0.8 s (Standard deviation of 0.2 s)
  - Speed error: Gaussian distribution with 95% confidence interval of -6 ~ +6 km/h, -12 ~ +12 km/h, or -12 ~ 0km/h

  *Position error with the uniform distribution of ±1 m is considered simultaneously
- Results
  - **With the negatively biased speed error, support effectiveness decreased**
    - The support effectiveness is greatly decreased especially in the scenario with the delay of 0.8 s and the speed error of -12 ~ 0km/h
  - **With non-biased speed errors, support effectiveness improved**
    - Especially in the scenarios with large delay

Number of merging without enough room

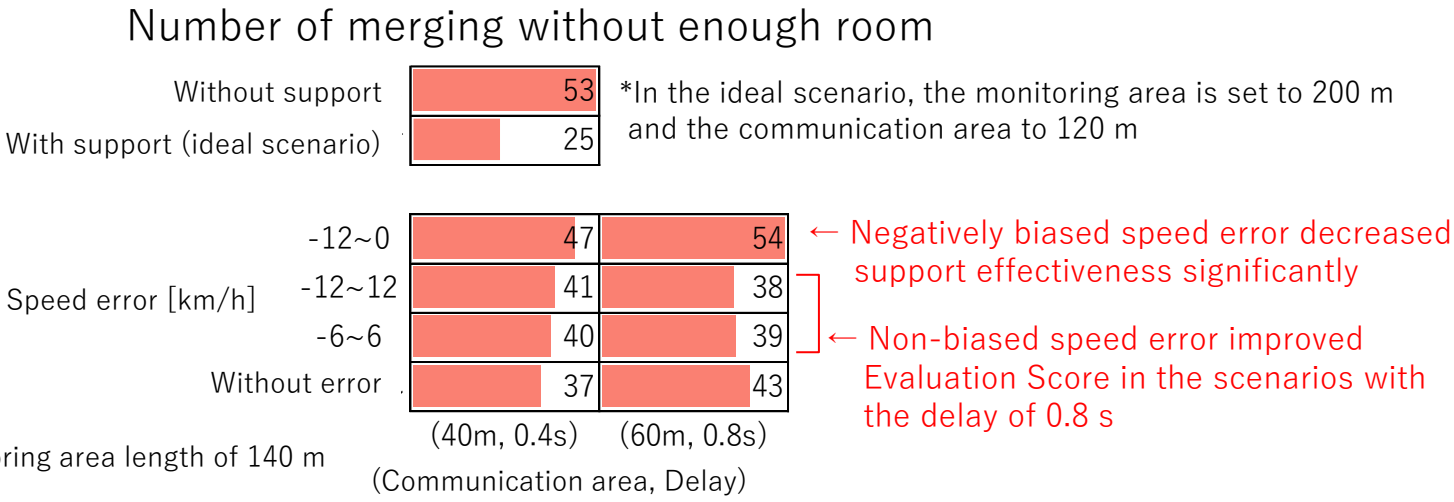


# Combination of Area, Information Delay and Error



- 2 x 3 x 1 (6 in total) scenarios as following
  - (Monitoring area, Communication area, Delay):
    (140 m, 40 m, 0.4 s) or (140 m, 60 m, 0.8 s)
  - Speed error: Gaussian distribution with 95% confidence interval of -6 ~ +6 km/h, -12 ~ +12 km/h, or -12 ~ 0km/h

  *Position error with the uniform distribution of ±1 m is considered simultaneously
- Results
  - **With the negatively biased speed error, support effectiveness decreased significantly**
  - **With non-biased speed errors and the delay of 0.8 s, support effectiveness improved**

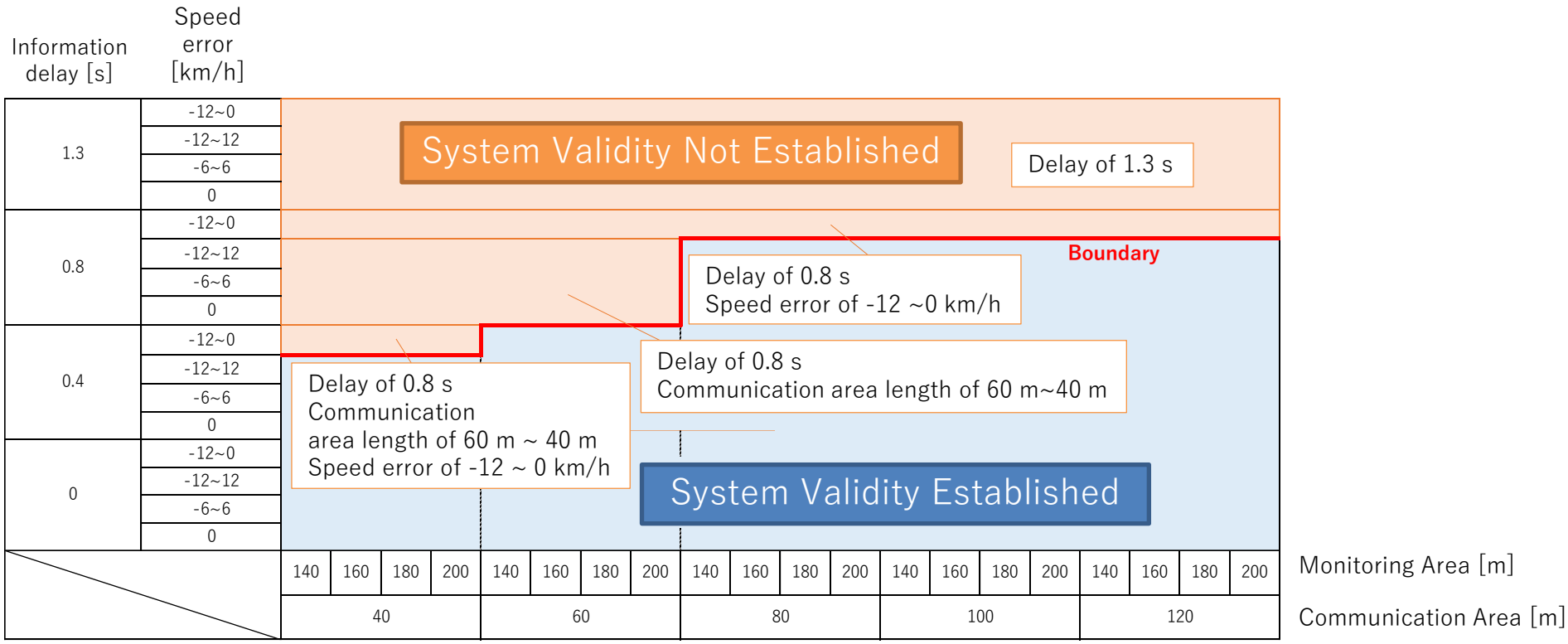


# Summary of combination analysis of Multiple System Conditions

Innovating for a Wise Future
構造計画研究所
KOZO KEIKAKU ENGINEERING Inc.

The table shows the acceptable conditions for the Day2 system

*Preliminary definition of system validity: The number of merging without enough room is reduced by 20% or more compared to the scenario without the support



# 5. Future Issues

# Future Issues



1. Re-organization the Evaluation Score concept
   - In some cases, the Evaluation Score value did not match decisions by human
   - Reorganizing and improving the concept of Evaluation Score enables more convincing evaluation
2. Re-evaluation after improving reproducibility of vehicle behaviors upstream on the main line
   - In this analysis, vehicle behaviors upstream on the main line was based on the default behavior of the simulator
   - The reliability of the evaluation can be improved by acquiring the actual traffic data, building the behavior model reproducing the data, and evaluating the feasibility of the Day2 system based on the model
3. Focusing on the saturated traffic condition
   - In this analysis, the evaluation was performed inclusively on whole time range with standard traffic flow
   - Evaluation focusing on the time range with dense traffic flow (saturated traffic) on the main line is desirable
4. Evaluate the Day3 system concept
   - This analysis focused on the Day2 system
   - Evaluate the the Day3 system effectiveness for merging situations that were not improved by the Day2 system

This report documents the results of Cross-ministerial Strategic Innovation Promotion Program (SIP) 2nd Phase, Automated Driving for Universal Services (SIP-adus, NEDO management number: JPNP18012) that was implemented by the Cabinet Office and was served by the New Energy and Industrial Technology Development Organization (NEDO) as a secretariat.