JAPAN AUTOMOBILE RESEARCH INSTITUTE

Appendix-A
SAKURA Methodology

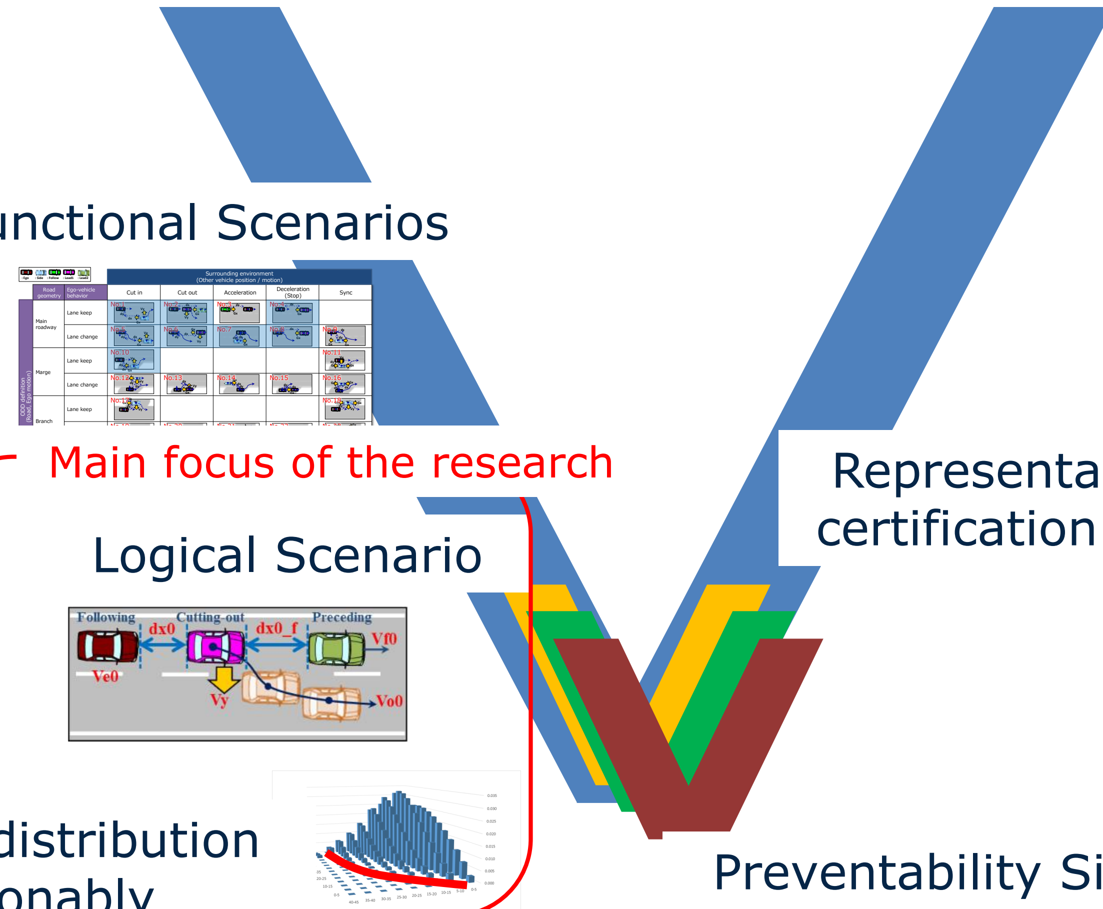
SAKURA
Safety Assurance KUdos for Reliable Autonomous Vehicles

SAKURA methodology

Actual world
Comprehensive
Complicated

Analysis
Decomposition

Model
Partial
Degenerated



Parameter distribution
& Reasonably
foreseeable range

Preventability Simulation
of each scenario

Synthesis
Integration

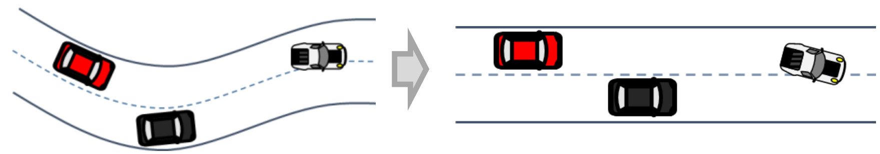
Logical Scenario Derivation Approach

Any of the 32 consolidated Functional Scenarios
(e.g. Cut-in, cut-out, and deceleration)

Foreseeable

1. Acquisition of real traffic data

2. Generation of vehicle behavior data

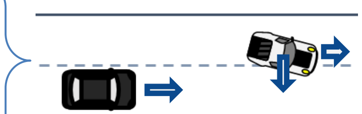


3. Definition of the required parameter ranges and limitations

- Ego's velocity
- Target's velocity
- Other's lateral velocity
- Vehicles distance

4. Extraction of targeted scenario scene

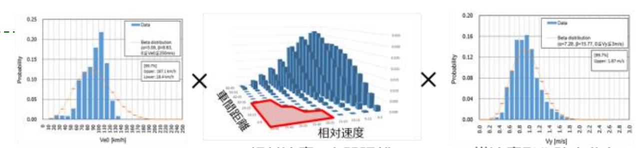
5. Extraction of parameter value



Relevant exposure

6. Estimation of parameter distribution

7. Setting of parameter range



自車速度発生確率分布 × 相対速度×車間距離発生確率合成分布 × 横速度発生確率分布

Derivation of Reasonably Foreseeable
Logical Scenario combinations

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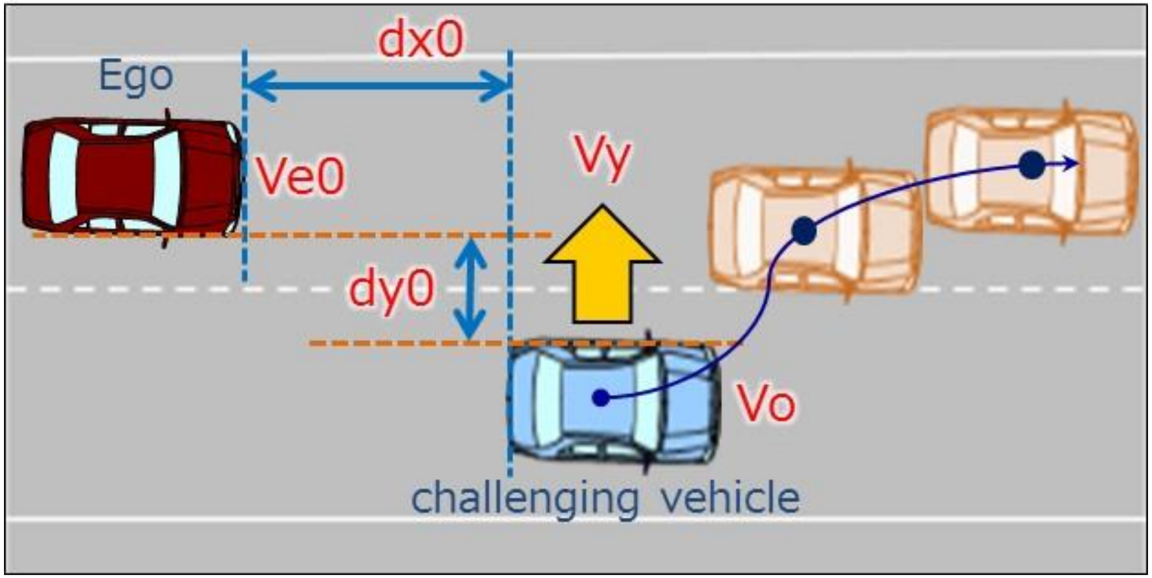
Estimation of parameter distribution

We used Cut-in scenario as an example



- VuT Long. Speed : Ve0(Initial)
- Relative Long. Speed : Ve0 - Vo (Initial)
- ChV Lateral Speed : Vy (Max.)
- Long. Distance : dx0 (Initial)

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Estimation of parameter distribution

2 β distribution estimation 1/2

Set upper/lower limit based on following principles

1. Constraint of mechanical dynamics
2. Assume ADS comply with the traffic rules
3. Interaction with other traffic participants

If the requirements under 1. don't suffice, consider 2 and 3 in order

Cut in parameter ranges are summarized as follows

VuT Long. Speed : $0 < Ve0 \leqq$ Speed limit （Regulation）

Relative Long. Speed : $0 < Vo0 \leqq Ve0$ （Definition of cut-in scenario）

ChV Lateral Speed : $0 < Vy \leqq 5$ [m/s] （Limit of Road-Tire interaction）

Long. Distance : $0 < dx0 \leqq 100$ [m] （Japanese guideline at 100km/h）

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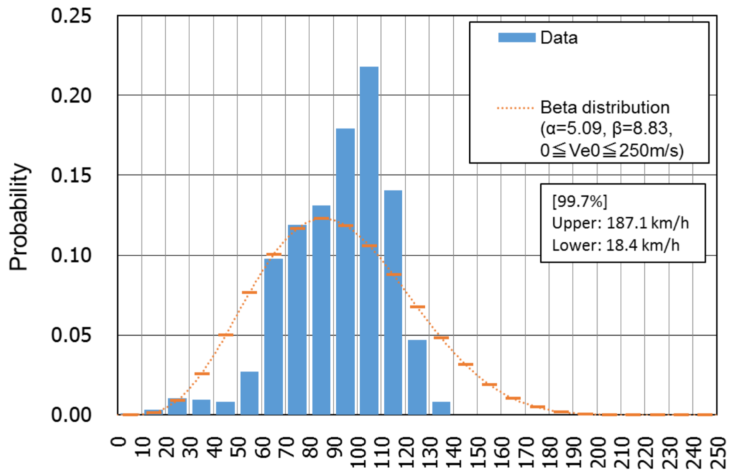
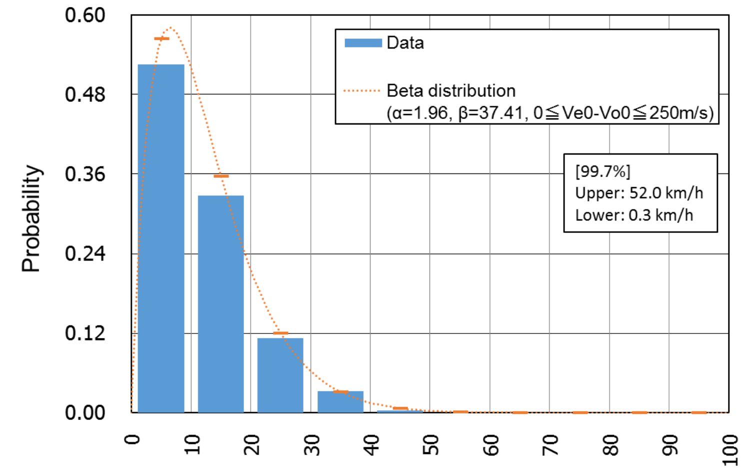
Estimation of parameter distribution

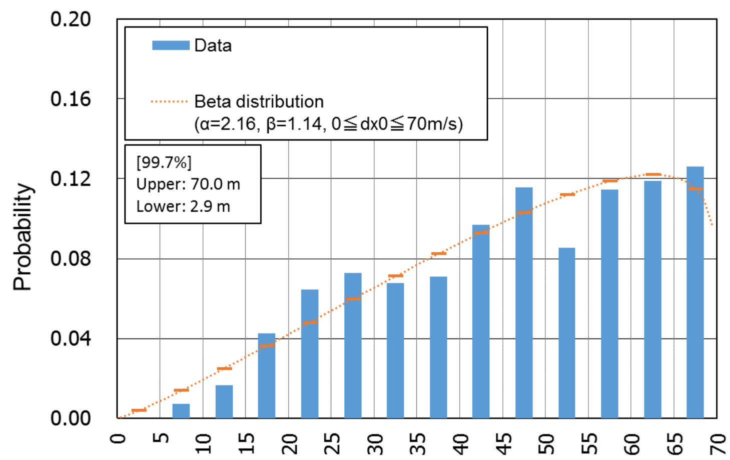
2 β distribution estimation 2/2



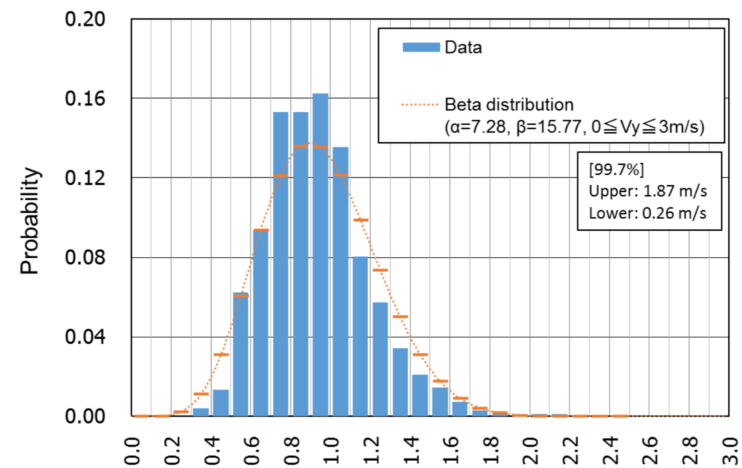
VuT Long. Speed



Relative Long. Speed



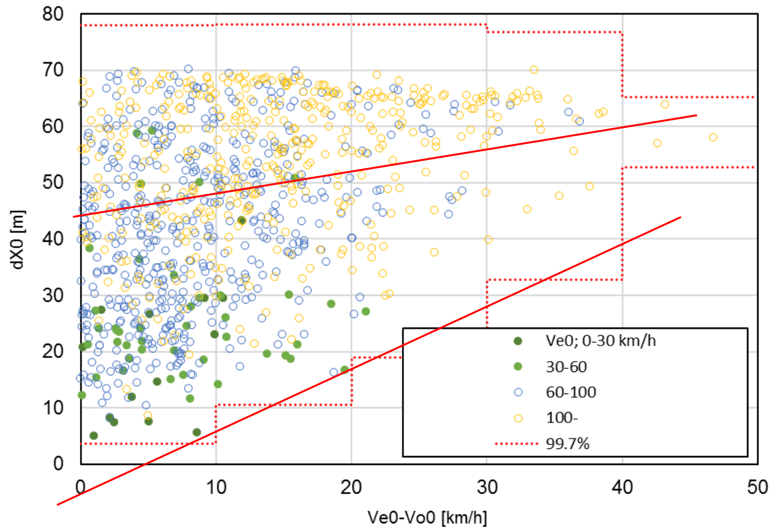
Long. Distance

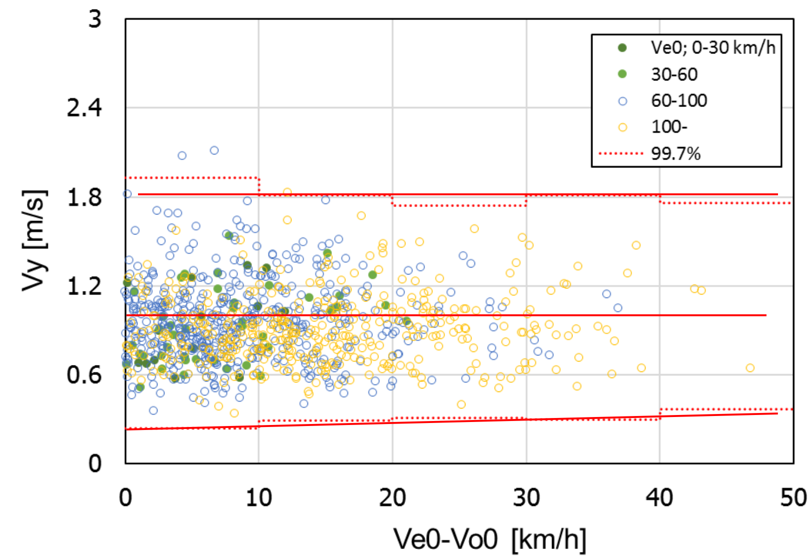


Lateral Speed

Estimation of parameter distribution

3 Evaluation of cross correlation





- Cross correlation is evaluated with gradient of mean value and 99.7 percentile value by each class
  - Relative speed and distance are correlated
  - Lateral velocity is not correlated with other parameters

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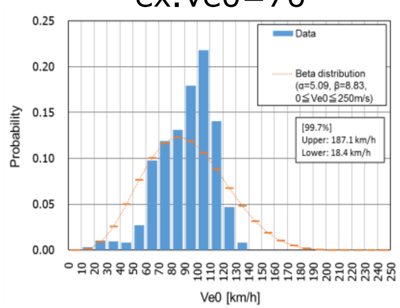
Estimation of parameter distribution

4 Synthetic β distribution considering cross correlation

- Synthetic (2 dimensional) β distribution for Vrel0 and dx0
- Independent β distribution for Vy

ex.Ve0=70



自車速度発生確率分布

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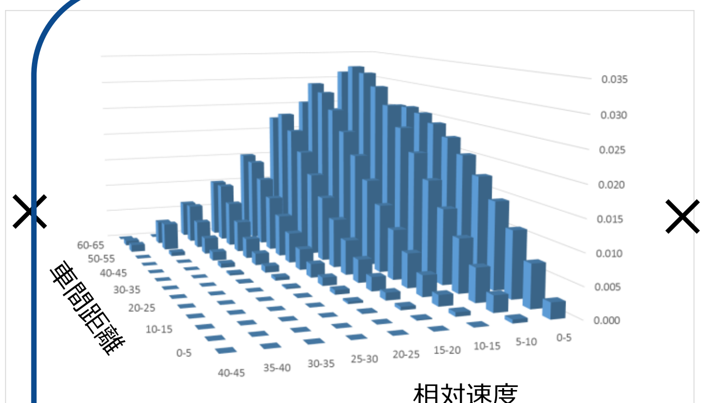

相対速度×車間距離
発生確率合成分布

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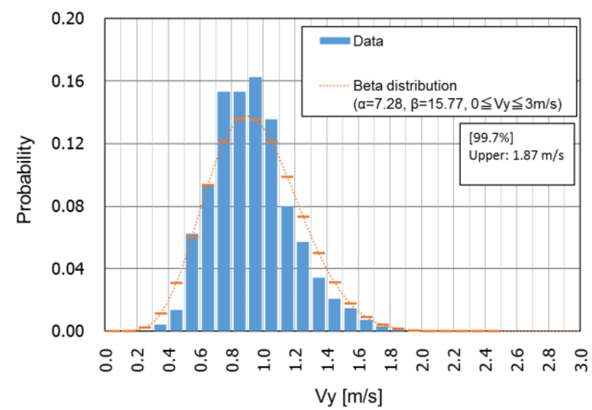
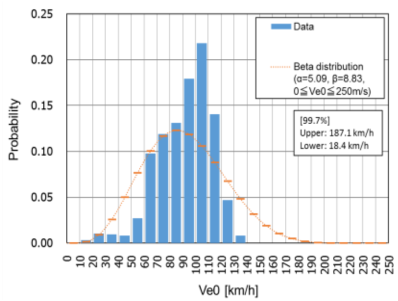


横速度発生確率分布

Encounter Probability of Vo, Vy and dx0 combination is estimated

Estimation of parameter distribution

5 Parameter range reduction based on risk acceptance



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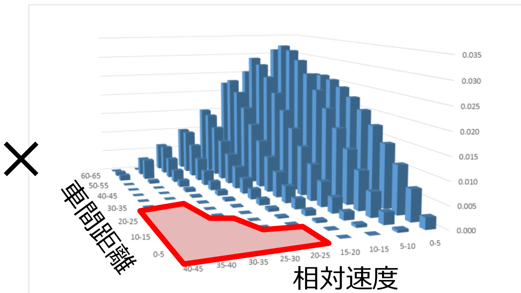

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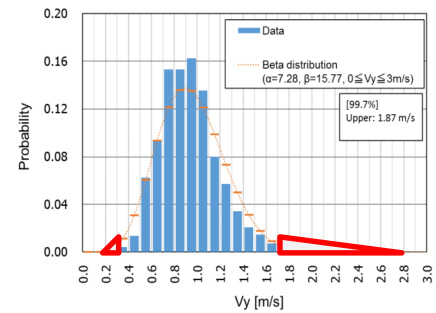

- Reasonably Foreseeable range can be determined by social risk acceptance level in each country※ (refer appendix)
- Red highlighted area is an image of unforeseeable range

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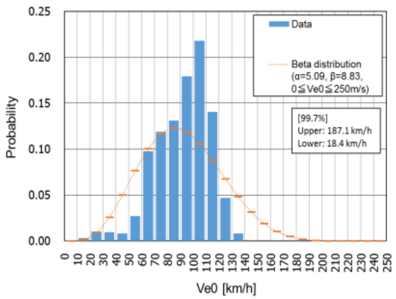
Estimation of parameter distribution

5 Parameter range reduction based on risk acceptance



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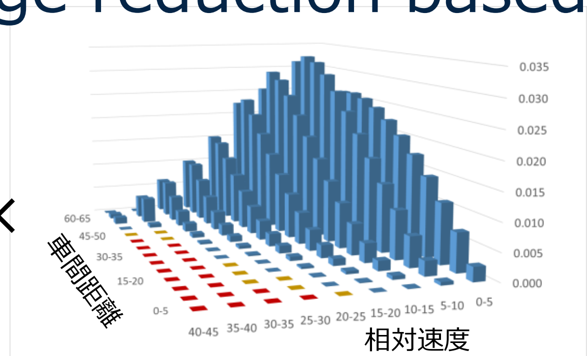

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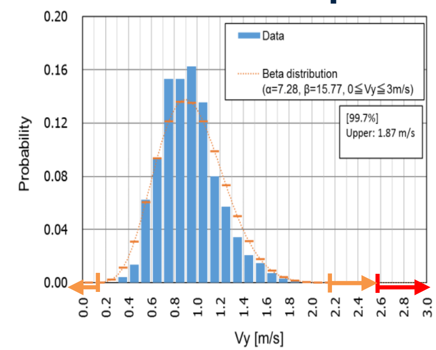


- e.g. Exclude 10^{-6} encounts/year (of an average driver)※
  - Red area can be excluded independently
    - Lateral Speed more than 2.6m/s

      or
    - Distance 0～5m and Rel. Speed more than 25km/h
  - Orange area can be excluded when both are in that range
    - Lat. Speed more than 2.2m/s and Dis. Closer than 20m and Rel. Speed more than 30km/h

※"Encount" probability (not risk).

A1. Stance on Risk acceptance

- **Basic Risk Classification（England HSE,ALARP）**
  - Broadly acceptable risk
  - Tolerable risk
  - Unacceptable risk

- **Tolerable Risk Defined in Guide 51**

Level of risk that is accepted in a given context based on the current values of society.

→Although it is difficult to define with universal and quantitative values (such as individual annual mortality)

HSE's Reducing Risks Protecting People（R2P2）whereas the upper limit is an accident that kills 50 people once every 5000 years.

A1. Stance on Risk acceptance

Guide51 outline

◆ Risk analysis

Represents a quantitative amount of risk included in the designed system.

Expresses the product's hazard occurrence frequency and estimates the damage extent.

◆ Risk Assessment

Examines whether or not the analyzed safety risk objectives have been met, and if they have not, how have they been reduced.

◆ Safety Objectives

Performance objectives consist of inverting calculations linked to the death of individuals (injuries).

A1. Stance on Risk acceptance

Safety Goals Objectives When Building Nuclear Power Plants

- **Japan**

  With nuclear reactors acute mortality risk may not exceed (0.1%) significantly. In 2001 the Japanese mortality risk was 7.7×10^{-3}/per year with cancer accounting for 1/3, hence 2.4×10^{-3}/per year. This refers to not exceeding a value of approximately 10^{-6}/per year.

  Index 1: Core reactor damage frequency Index 2: Frequency of function loss for the reactor container

  The safety goal is the fulfillment of both indexes simultaneously

- **US**

  The mortality risk is the same as is Japan.

  Objective targets are based on core damage occurrences and early large-scale releases

- **England**

  Defined by the 2 steps, Basic Safety Levels (BSL) and Basic Safety Objectives (BSO)

A1. Stance on Risk acceptance

Method of Setting Safety Objectives for Railway Systems

◆ **In Japan**

GAMAB, close to Positive Risk Balance

◆ **International Regulations**

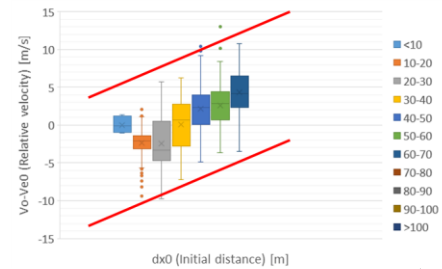
Based on the quantification of risk analysis (Absolute)

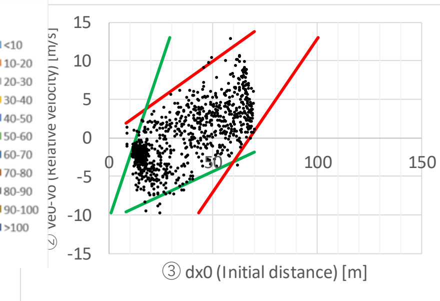
GAMAB or ALARP

Risk analysis method

FMEA, FTA, and others, most common

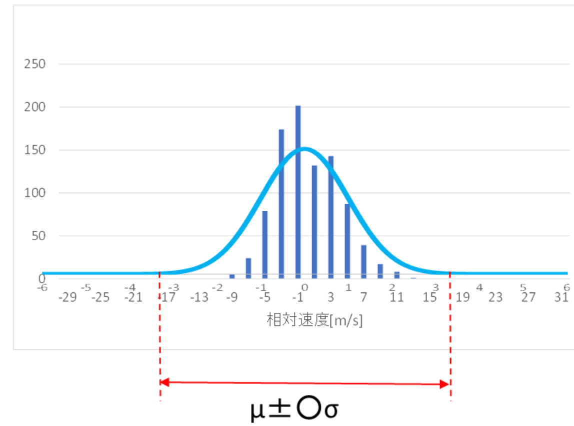
3. Parameter Distribution Estimation Method (pre-revision)





○Correlation Considerations

- Absence of causal nexus
- Linear regression by deriving μ±3σ for each rank
- Judgement based on inclination of the superiority test

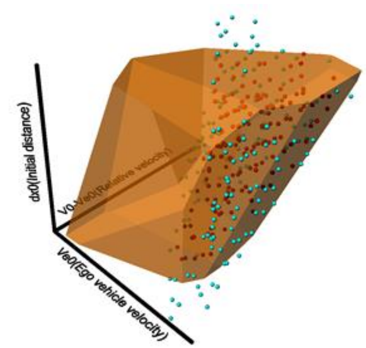


○ Range Extrapolation

- Assumption of infinite distribution of parameters (normal distribution)
- Parameter range of 3σ (behavior)

⇒ Parameter Range

- Correlation boundary shaped as a cut multidimensional cube



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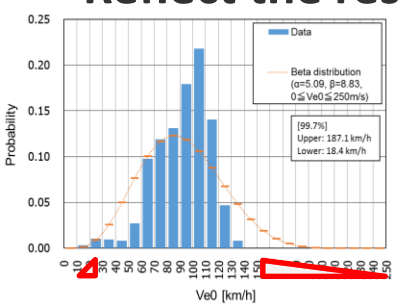
3.Estimation Method for Parameter Distribution (post revision)

○Consideration of Correlations

- Consideration of causal relation (Ego's behavior→ Relation to Target→ action)
- Linear regression by deriving μ±3σ for each class
- Judgement based on inclination of the superiority test

○Extrapolation of range

- Assuming a finite distribution (β distribution) (higher limit/lower limit)
- Estimating the probability occurrence of the parameter combinations, while excluding rarely occurring combinations (e.g. Red frame in the figure below)
- Reflect the results in the parameter range (nonlinear!)



Ego's acceleration probability distribution

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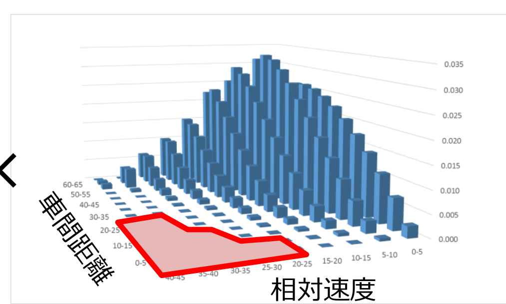

Target's velocity x vehicle distance Probability distribution occurrence composite

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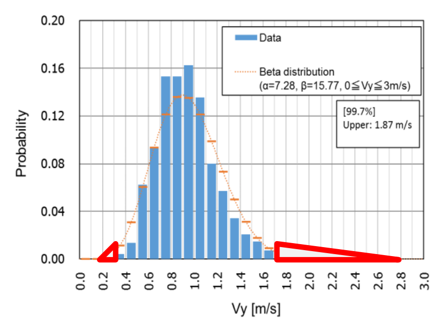

Lateral velocity probabily occurrence distribution

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