Cross-Ministerial Strategic Innovation Promotion Program (SIP) / Automated Driving for Universal Services (SIP-adus) / Research and Study of Common Reference Point (CRP) in High-Definition Map

FY2020 Report (Summary)

Mitsubishi Research Institute, Inc.

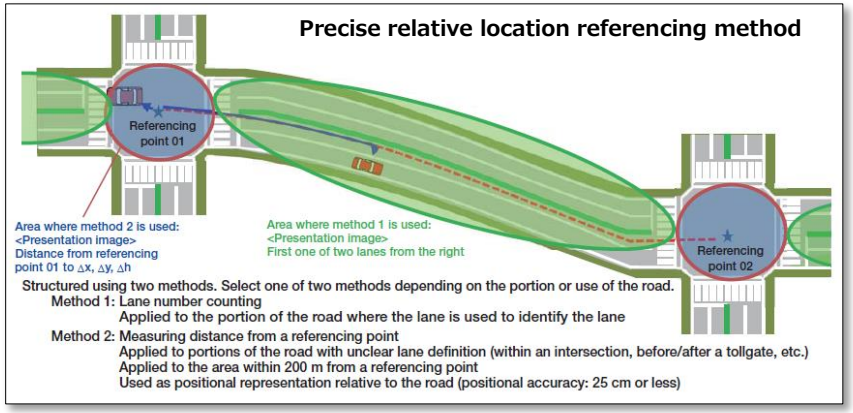
Background / Issues

【Background】

- It is not realistic to expect that all High-Definition Maps (HD Maps) for automated driving will be unified.
  - Each of HD Maps is based on different mapping rules (method, accuracy, density, period of survey, error range, etc.). Therefore, there is always possibility of slight gap between maps.
- It is necessary to create method of precise representation of relative location by which vehicles and other entities can have common recognition.

【Issues】

- Although there is an international standard for the representation of precise relative location, there are no common rules for reference points necessary for common recognition among different maps.
- In this study the needs of the rule-based reference points (Common Reference Point; CRP) for automated driving are organized and the functional requirements and Implementation Items of CRP are examined.



<Examples of location representation using reference point>

Method1 : Lane number counting	Identifies the longitudinal location by using reference points or others installed at both ends of intersection and specifying the lane number. (e.g.); Lane No.X, XXm from CRP-01 to -02
Method2 : Measuring distance from referencing point	Identifies detailed location by the distance from reference point, etc. at intersections (e.g.); XXm east, XXm north from CRP-01

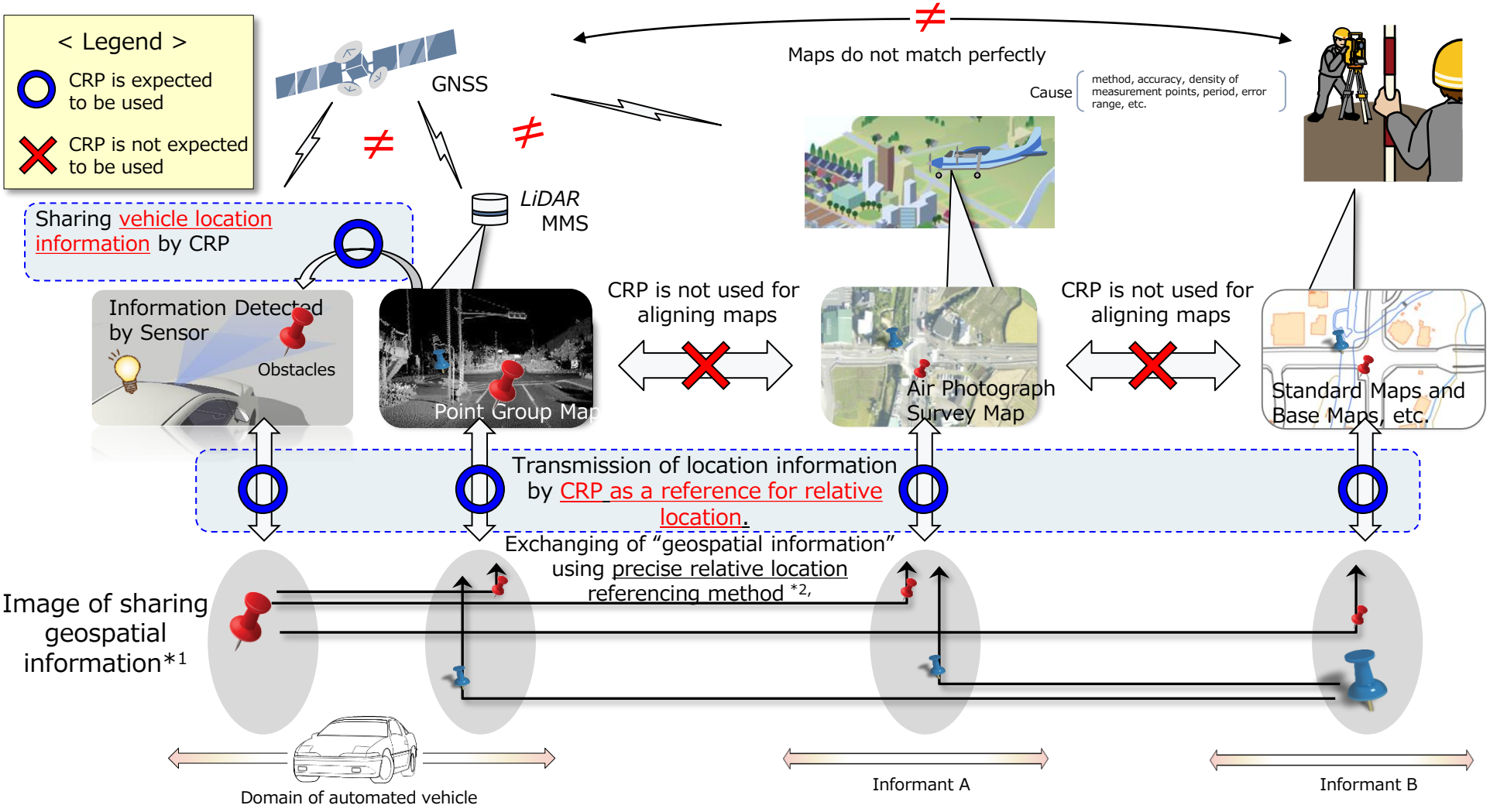
Source) ITS Standardization Activities 2019、Society of Automotive Engineers of Japan, Inc.
https://www.jsae.or.jp/01info/org/its/its_2020_en.pdf

*ISO17572-4 2019 : Intelligent transport systems (ITS) — Location referencing for geographic databases — Part 4: Precise relative location references (precise relative profile)

*1 Geospatial Information: Information which includes location as an attribute (e.g. dropped objects, damaged areas, existence of other vehicles, etc.)
*2 Precise relative location referencing method: method of representing location by its relative distance from reference point, not by absolute location

(Reference) Utility of CRP

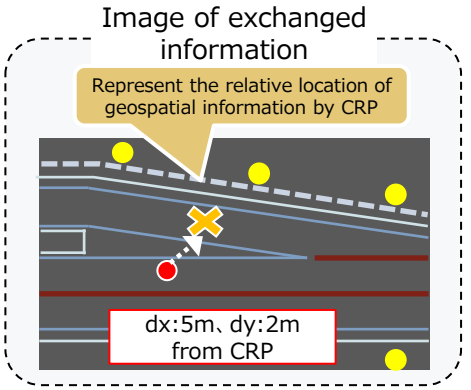
- The purpose of CRP is to transmit the relative locations of the "geospatial information*1" represented on each map, not to align different maps.



Source) ・"Air Photograph Survey Map", "Standard Maps and Base Maps": Tile-based GSI map made by Geospatial Information Authority of Japan
・"Point Group Map": MLIT "Collection of 3D road data by on-vehicle sensing devices has started - to expedite the examination of special vehicle traffic permits -" (https://www.mlit.go.jp/common/001247574.pdf, taken on 24/2/2021)
・Other information: made by Mitsubishi Research Institute

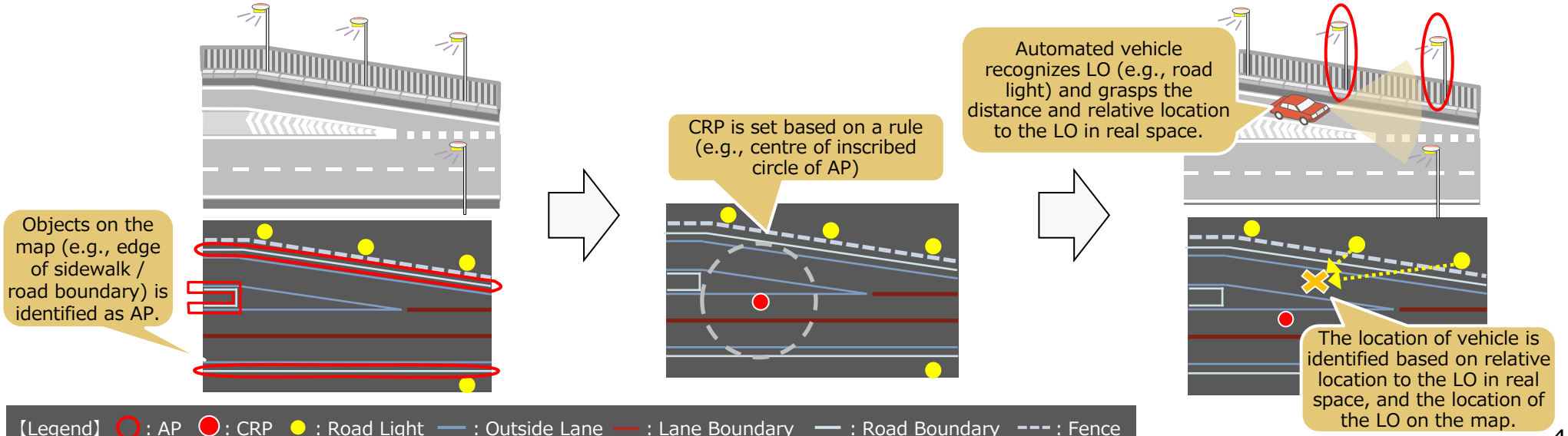
(cf.) LO, CRP and AP

- CRP (virtual object) is placed on the map as a reference point for relative location. The location of CRP is defined from real objects (AP) on the map.⇒①
- In automated driving, LO (Localization Object) is used to identify the vehicle location on a map. The vehicle can recognize the location information (e.g., dropped objects, traffic congestion, vehicle location, etc.) by CRP.⇒②



①Installation of CRP　②Automated Driving

	AP (Anchorage Point)	CRP (Common Reference Point)	LO (Localization Object)
Definition	Point used to define CRP location	Reference point used to represent the location of section/point	Point used to identify the location of vehicle on HD Map
Real/Virtual	Real	Virtual	Real
Visibility from Mobil Mapping System	Necessary	Unnecessary	Necessary
Visibility from Automated Vehicle	Unnecessary	Unnecessary	Necessary
Absolute Coordinate	About the same accuracy as the map where CRP is placed	Depends on AP accuracy	Depends on the map where LO is placed



Topics and Results of this Study (Summary)

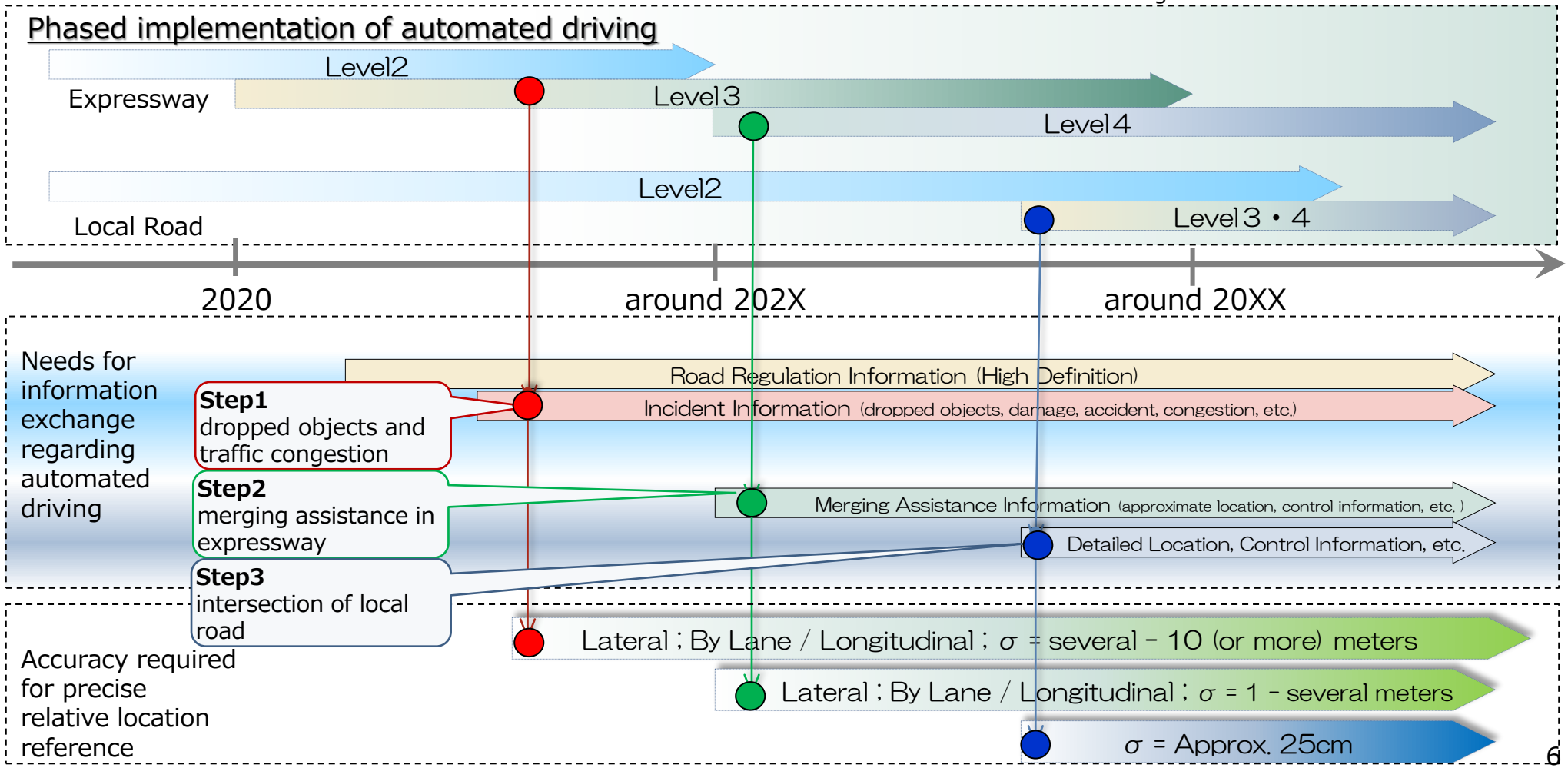
Topics	Study Results	Page
1. Needs for exchanging location information by CRP	According to the phases of automated driving, needs for exchanging location information by CRP are organized in 3 steps.	6
	Use case examples in which CRP is utilized at each step are organized. ➢ Step1 (Dropped objects and traffic congestion) ➢ Step2 (Merging assistance in expressway) ➢ Step3 (Intersection of local road)	7～9 (7) (8) (9)
2. Functional requirements and implementation items regarding CRP	Functional requirements of CRP expected at each step are organized. (Method of location representation / Relative accuracy of information / Areas where CRP is required / Required accuracy of map)	10
	CRP-related implementation items at each step are organized. (Relationship between objects used as AP / Installation method of CRP / Management method of CRP)	10 (10～11)
3. Case study	Case studies for the use cases of CRP are organized, hypothesizing the demonstration experiment under SIP-adus ➢ Step1 (Dropped objects and traffic congestion): Road traffic information by lane ➢ Step2 (Merging assistance in expressway): Merging assistance information	14 (15) (16)

* This study is a technical study. This study does not determine the operation of CRP or the method of the demonstration experiment itself.

1. Needs for Exchanging Location Information by CRP

- As the automated driving system gets implemented, the situation where common recognition between different maps is required is expected to change.
- The needs assumed to arise in each phase of automated driving are organized.

*CRP use cases to be implemented will be studied considering the demonstration experiments based on the case studies.
*The utilization of CRP in the situation other than automated driving will also be considered in the future.

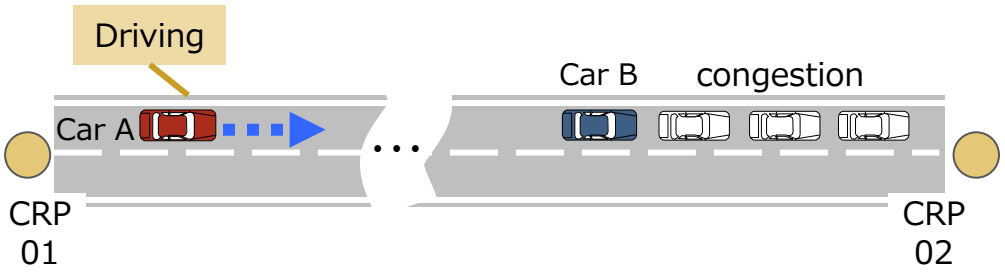


Step1 (Dropped Objects and Traffic Congestion)

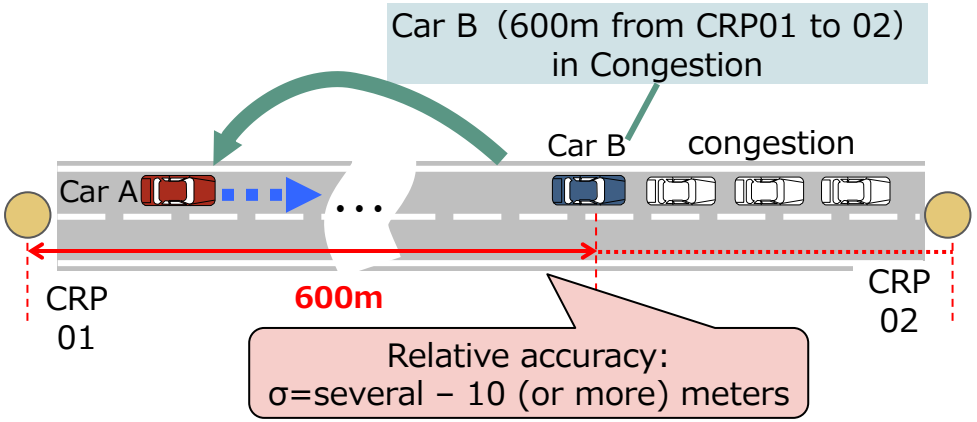
(Example) d-3. Driving assistance based on traffic congestion information*

: Reference point (CRP)

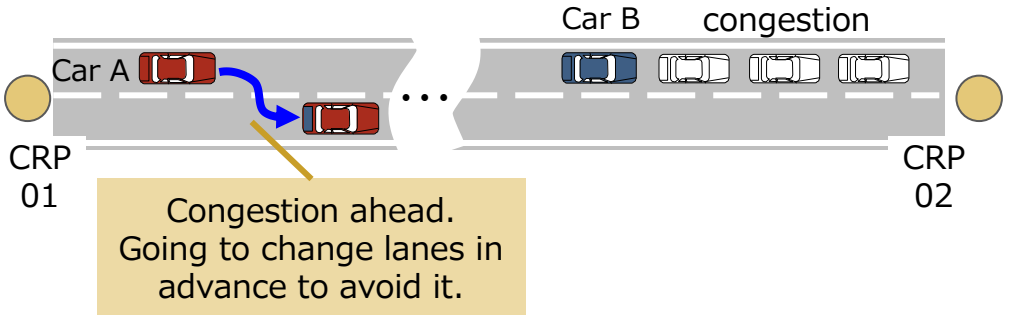
①Traffic congestion ahead of Car A in its lane.



②Information about congestion obtained by vehicle in congestion (Car B) is transmitted to Car A.



③Car A changes lanes in advance based on the information transmitted from Car B.



Car A changes lanes in advance, not just before the congestion. It is assumed that **the standard deviation (σ) of relative accuracy of information can be several – 10 (or more) meters**.
(Even if the information on the location where the congestion starts (600m) is incorrect by about 50m, the way to control Car A will be the same: "Change lanes from 500m ahead of congestion.")

* Reference: "SIP Use Cases for Cooperative Driving Automation - Activity Report of Task Force on V2X Communication for Cooperative Driving Automation in FY2019 - "

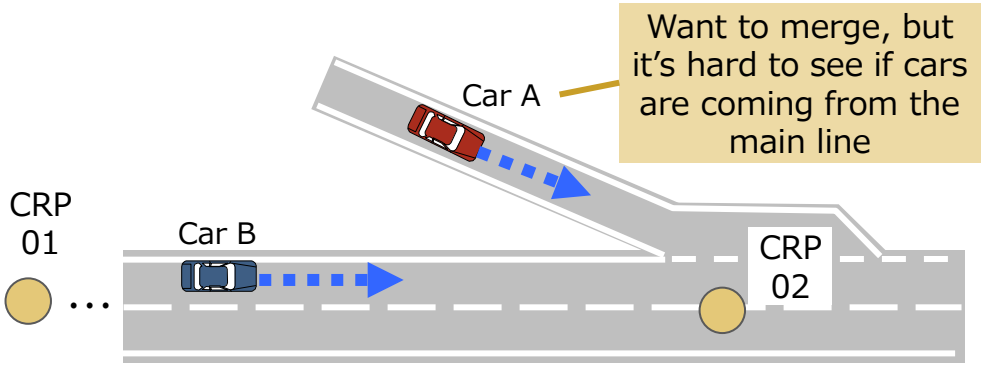
Example of location representation by Method1.
Location representation by Method2 is also possible

Step2 (Merging Assistance in Expressway)

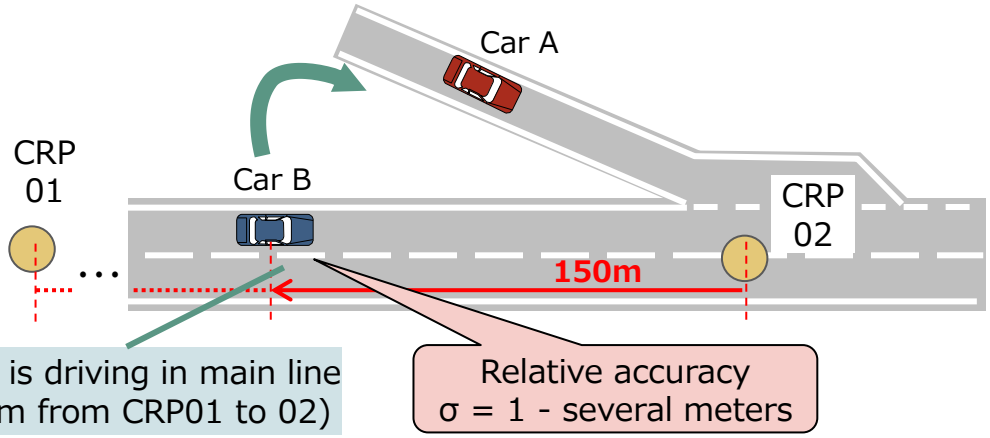
(Example) a-1-3. Cooperative merging assistance with vehicles on the main lane by roadside control*

: Reference point (CRP)

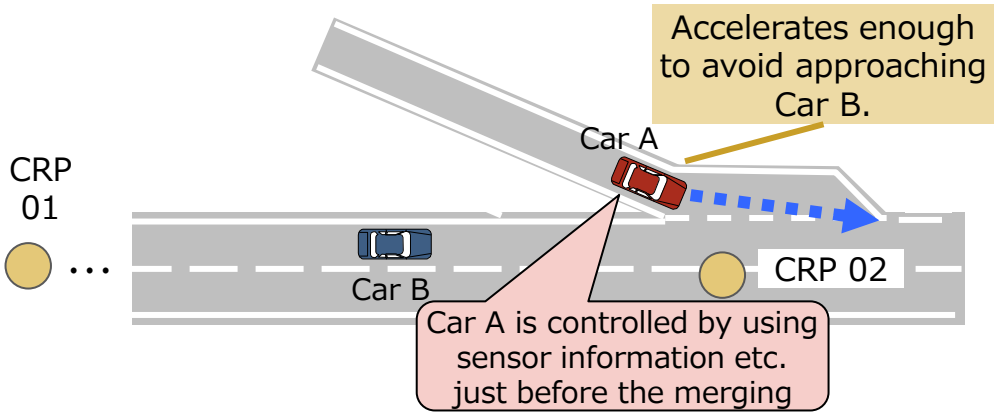
① Car A enters the main line from the merging lane.



②The location, speed and plan of the vehicle driving on the main line (Car B) are transmitted to Car A.



③Car A adjusts its speed based on the information transmitted from Car B.



Car A adjusts its speed a few seconds before the merging based on the location of Car B. It is assumed that **σ of relative accuracy of information can be 1 - several meters**.

(Even if the information on Car B's location (dx = -150m) a few seconds before the merging is incorrect by about 5m, Car A's control remains the same: "Accelerate to XX km/h in a few seconds." Emergency control just before merging is based on sensor information, not on CRP-based location representation)

(Assumptions: Car A and Car B are time-synchronized.)

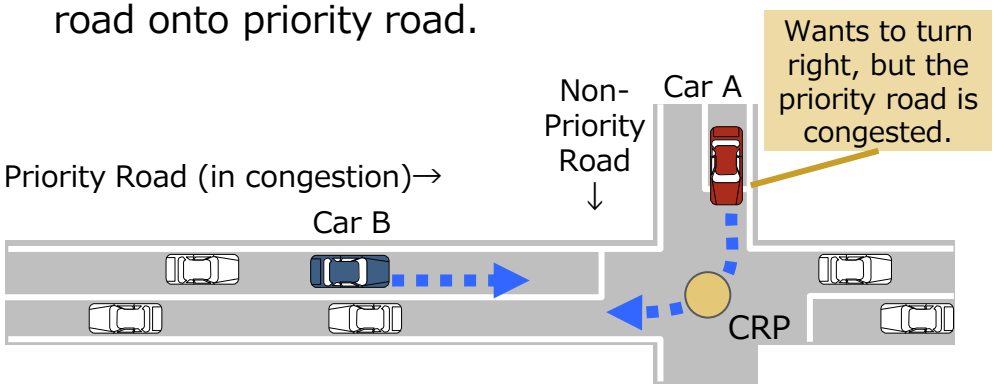
* Reference: "SIP Use Cases for Cooperative Driving Automation - Activity Report of Task Force on V2X Communication for Cooperative Driving Automation in FY2019 - "

Step3 (Intersection of Local Road)

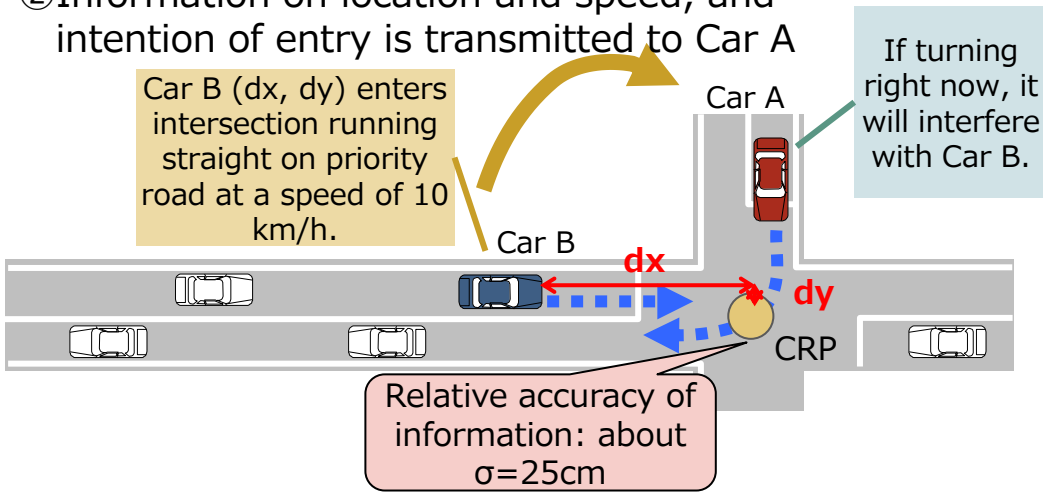
(Example) a-3. Entry assistance from non-priority roads to priority roads during traffic congestion*

: Reference point (CRP)

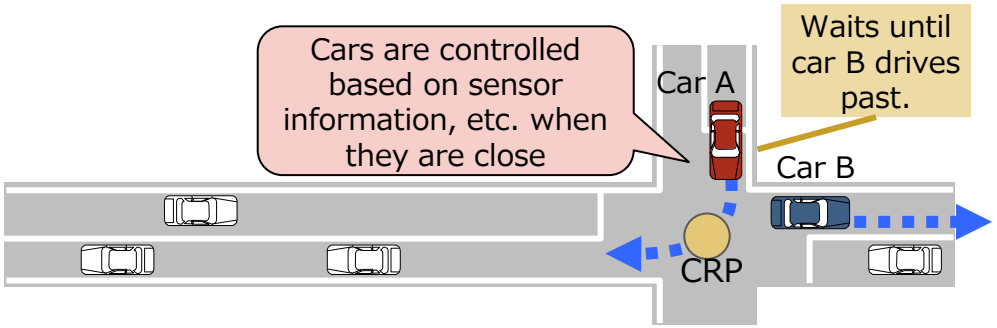
①Car A intends to turn right from non-priority road onto priority road.



②Information on location and speed, and intention of entry is transmitted to Car A



③Car A decides whether to enter the intersection based on the information transmitted from Car B.



Car A is controlled based on the real-time location information of Car B. **σ of relative accuracy of information is required to be σ = 25cm**.

(When determining if Car A enters the intersection, the location of Car B must be represented with high accuracy. The cars are controlled based on both CRP-based location representation and sensor information.)

(Assumptions: Car A and Car B are time-synchronized.)

* Reference: ”SIP Use Cases for Cooperative Driving Automation - Activity Report of Task Force on V2X Communication for Cooperative Driving Automation in FY2019 - ”

2. Functional Requirements and Implementation Items of CRP

- It is effective to use CRP as reference point at any step of automated driving phase.
- The expected functional requirements differ according to the needs.

(Functional requirements for each step)

	Step1	Step2	Step3	
Needs	Dropped objects and traffic congestion, etc.	Merging assistance in expressway	Intersection of local road	
Method＝	1 (Lane number counting) Identify the longitudinal location by using reference points installed at both end and specify lateral location by showing the lane number.		2 (Measuring distance) Identify detailed location by the distance from reference point.	
Relative Accuracy of Information (σ)	several – 10 (or more) meters	1 - several meters	Approx. 25cm	
Image of required number of control point (reference point)	Sufficient reference point ≒ Required number of CRP Every branch merging section of intersections and ICs Major intersections and ICs Areas where CRPs are installed should be determined as functional requirements determines			dense ↑ installation density ↓ sparse
Required map accuracy	Medium scale	Large scale	High Definition	

○Implementation items for each stage are organized, considering the functional requirements of CRP for each step.

○Examples of installation method of CRP are organized.

(Implementation Items)

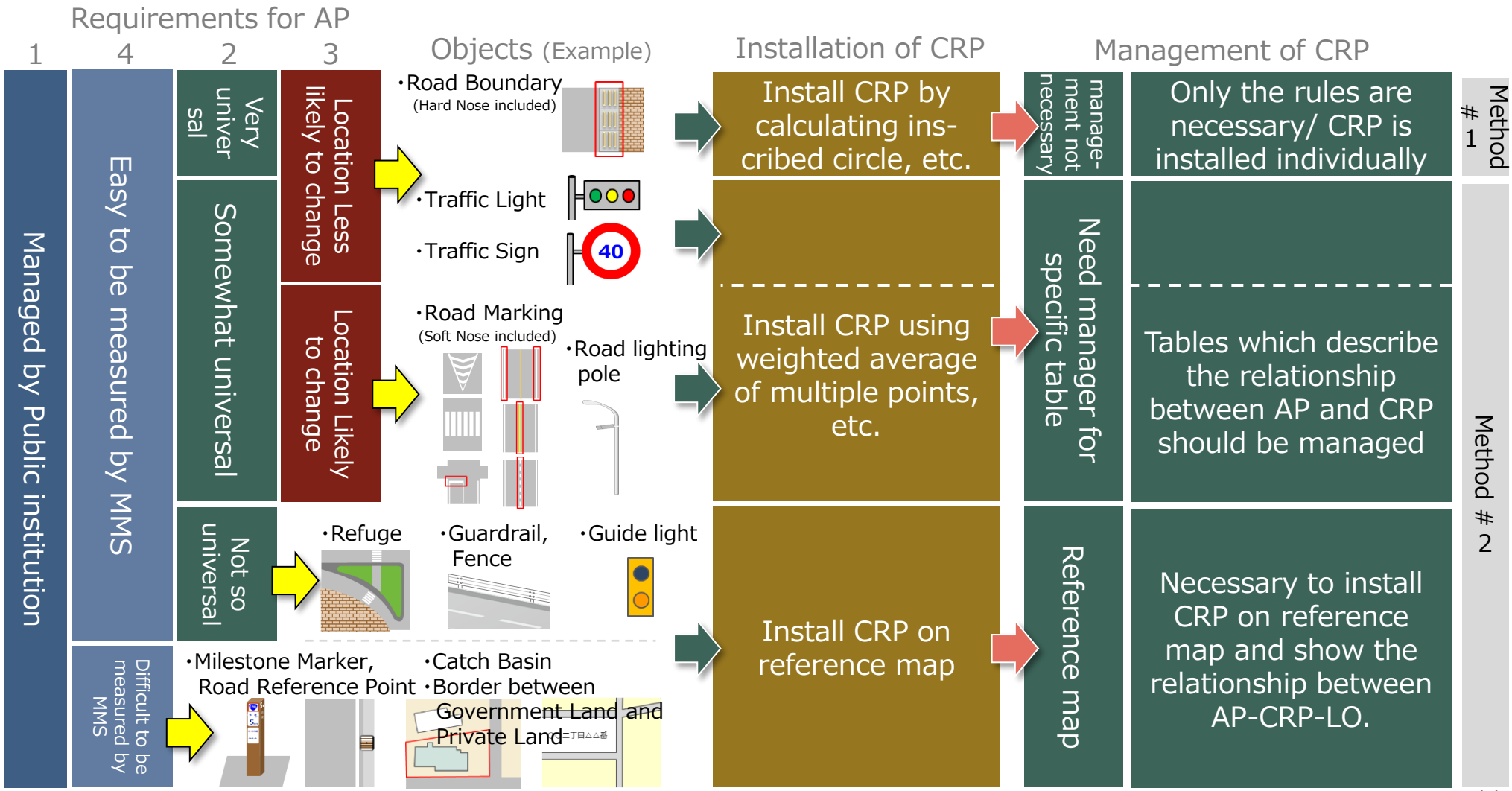
Implementation Items on CRP	(Issues of HD Maps)→ Determine requirements for mapping rules.	accuracy assurance
	Define how to install CRP.	common definitions
	(Issues of CRP) Determine common names or IDs.	common names

Step1; Identifying unique names or IDs to intersections and branch merging sections. (e.g. IDs used in existing network data)
Step2; Establishing rules for determining CRP locations in the field and on the graphic. (See “Group of Objects of AP”)
Step3; Define the criteria for mapping for HD Maps so that the relative accuracy by CRP falls within σ = 25 cm.

* This study does not decide which objects are appropriate as AP.

Objects of AP / Installation and Management CRP

- In Step2 and Step3, the location of CRP is defined from real objects (AP) placed around CRP.
- How to install and manage CRP differs by each group classified according to requirements for AP.



(cd.) Rule for CRP Installation (Draft)

(Example) The center of the inscribed circle of “Road Boundary" is set as CRP

(1) Objects of AP

At branch merging sections or flat crossings, road boundary is identified as AP.

(2) Location of CRP

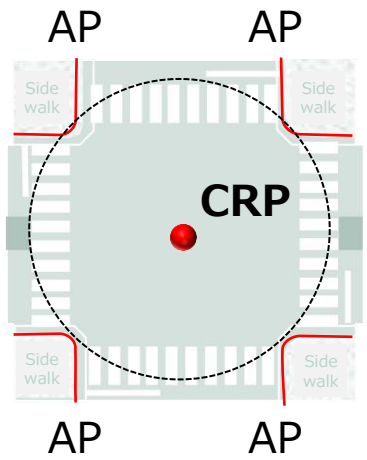
CRP is set at the center of the largest inscribed circle among the circles which meets both Requirement 1 and Requirement 2:

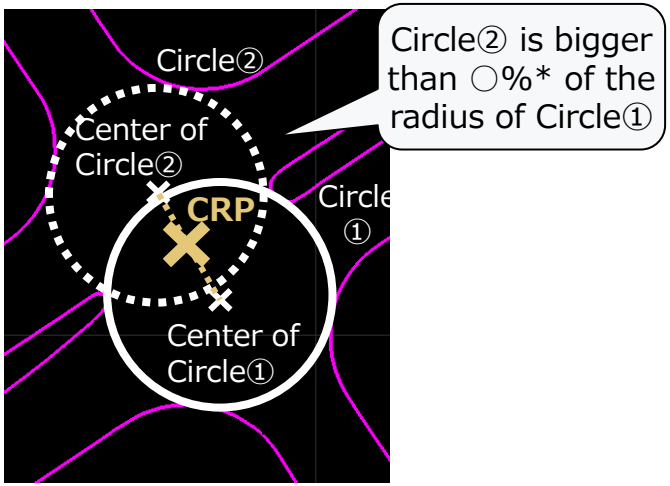
Requirement 1 - circles which touch the road boundary at 3 points

Requirement 2 – circles which exist inside the branch merging section or flat crossing.

At the point where there are multiple inscribed circles which are close in radius to the largest circle exceptional procedures should be taken:

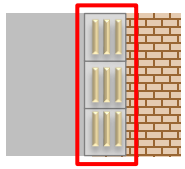
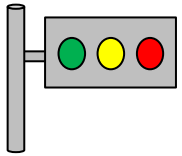
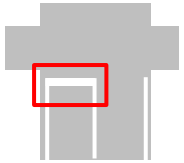
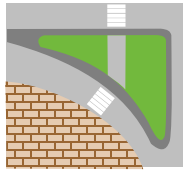
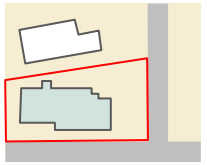
(e.g.) the gravity of the centers of the circles which is at least ○% of the radius of the largest circle is used as the CRP”.*





*Details of how to deal with exceptions (e.g., specific numbers for ○%) will be discussed in the future based on the relative accuracy of the map.

(cf.) Group of Objects of AP

Objects (examples)				Road Boundary	Traffic Light	Stop Line	Refuge	Border between Government Land and Private Land
Image								
Study Results on Requirements	1	Public institution manages the object		Managed by public institution				
	4	Easy to measure	• Easy to be measured by MMS • Difficult to be measured by MMS	Easy to be measured by MMS				Difficult to be measured by MMS
	2	Universally installed	• Very universal • Somewhat universal • Not so universal	Very universal	Somewhat universal		Not so universal	Very universal
	3	The location does not change in real world	• Likely to change • Less likely to change	Less likely to change		Likely to change	Less likely to change	Less likely to change
Other objects that belong to the same group (examples)				-	-	• Channelizing strip • Pedestrian crossing • Roadway outside line • Center line • Traffic lane boundary	• Guardrail, Fence • Guide light	• Location marker, Road reference point • Catch basin • Road edge

3. Case Study

Abstract

- Case study for the use cases of CRP is organized, hypothesizing to conduct at the SIP-adus demonstration experiments (Tokyo Waterfront Area Demonstration Experiment).
- Considering the current progress of automated driving technology, the case studies of Step1 (dropped objects, congestion) and Step2 (merging assistance in expressway) are organized.

  ⇒ Case study of Step3 (intersection of local road) will be carried out when the need for precise location representation at intersections of local roads increases due to the progress of automated driving technology.
- The study will be used in future demonstration experiments to verify the effectiveness, etc.

	Step1	Step2	Step3
Needs	Dropped objects and traffic congestion, etc.	Merging assistance in expressway	Intersection of local road
Method =	1 (Lane number counting) Identify the longitudinal location by using reference points installed at both end and specify lateral location by the lane number.		2 (Measuring distance) Identify detailed location by the relative location from reference point.
Relative Accuracy of Information (σ)	several – 10 (or more) meters	1 - several meters	Approx. 25cm

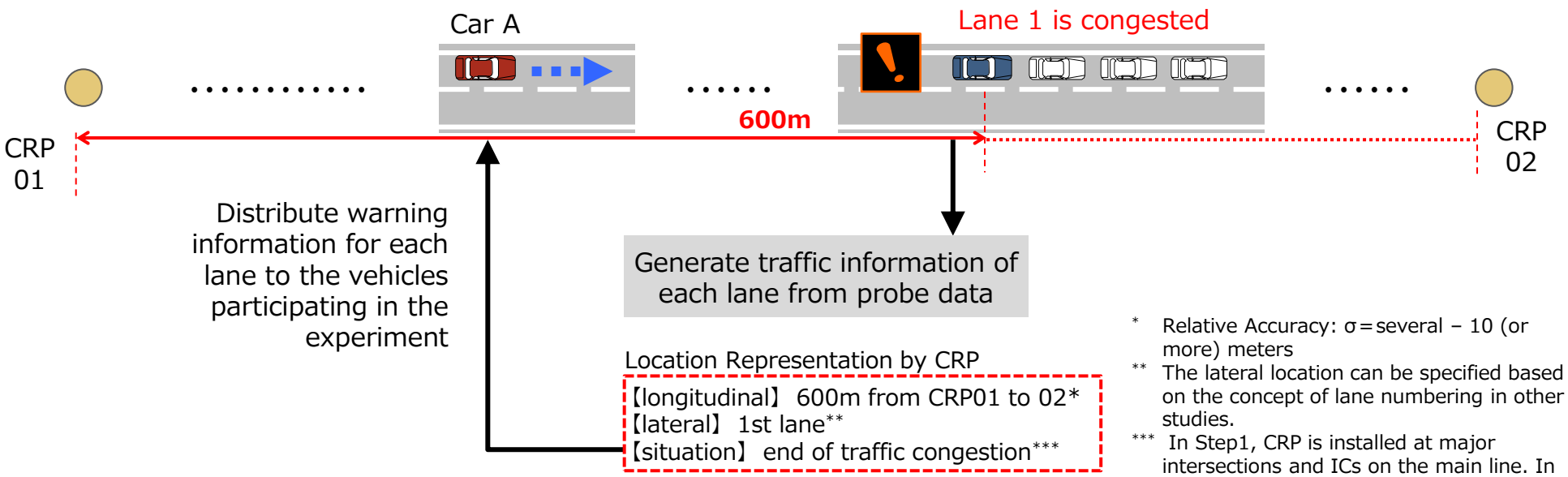
Step1 (Dropped objects, congestion) Case Study: Road traffic information by lane

Step2 (Merging assistance in expressway) Case Study: Merging assistance information

Step1 (Dropped Objects and Traffic Congestion): Road Traffic Information by Lane

- In the demonstration experiments of SIP-adus (2020) conducted at the Haneda Line and Bayshore Line of Metropolitan Expressway
  - The road traffic information of each lane generated from probe data was distributed to experimental server.
  - The location representation was converted to CRP-based * information and distributed to experimental in-vehicle unit. *The locations of CRPs were not based on AP-based studied in this document.
- As an example of Step1 (dropped objects and traffic congestion), it is possible to distribute information which describes the location by CRP * from the beginning in order to verify the effectiveness, issues, etc. of CRP.

*Verification can be done in 2 ways: 1) installing one CRP for each IC, 2) installing CRPs at any branches or merging points.



* Relative Accuracy: σ＝several – 10 (or more) meters

** The lateral location can be specified based on the concept of lane numbering in other studies.

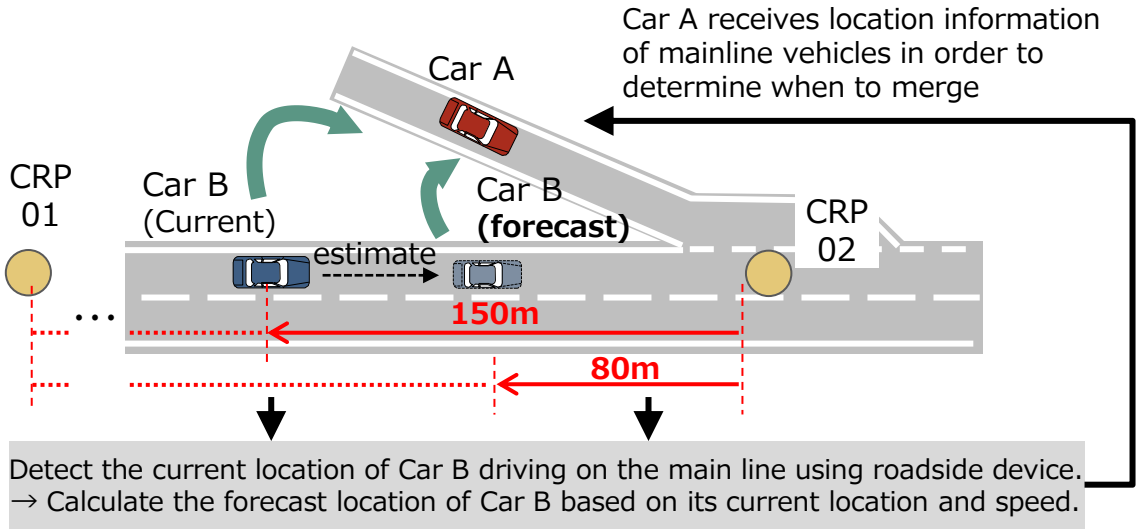
*** In Step1, CRP is installed at major intersections and ICs on the main line. In consideration of Step2, CRP can also be installed at each branch and merging point on the main line.

(Figure) Case Study of location Representation by CRP

Step2 (Merging Assistance in Expressway): Merging Assistance Information

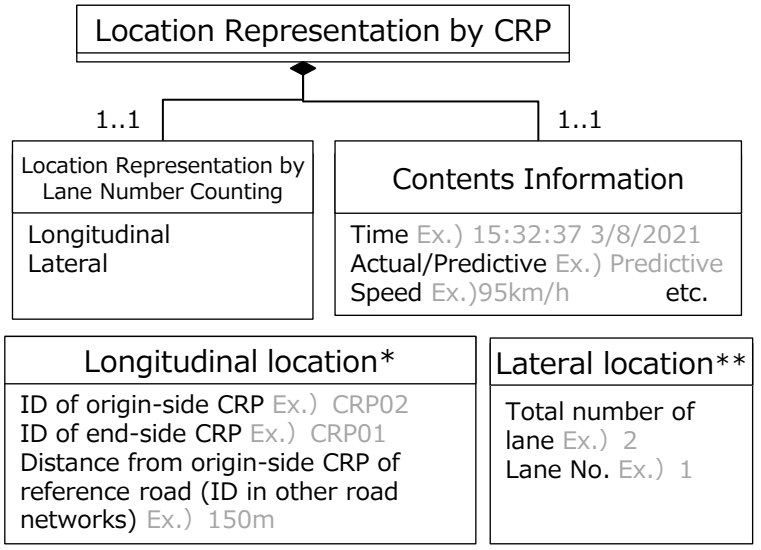
- In the demonstration experiments of SIP-adus (2019-20) conducted at the Airport West Interchange of Metropolitan Expressway Haneda Line, information about vehicles driving on the main line (merging assistance information) is provided to vehicles driving on the merging lane.
  *Traffic conditions on the main line were detected in lateral direction at the specific spot and the arrival time of the confluence is provided to the vehicle on the approach road side.

- As an example of Step2 (merging assistance in expressway), it is possible to distribute information about vehicles traveling on the main line (merging assistance information) to merging vehicles using CRP-based location representation in order to verify the effectiveness and issues of CRP.



Example of location representation by Method1 (Lane number counting)
(Representation by Method2 (Measuring distance) is also possible)

(Figure) Case Study of location Representation by CRP



* Example of location representation by Method1 (Lane number counting). In the case of Method2 (Measuring distance from reference point), the data model is different.
** The lateral location is specified based on the concept of lane numbering in other studies.

(Figure) Data Model of Distribution Data (Example)

4． Conclusion

In this study, the basic concept of CRP installation to exchange location information between different HD Maps. In addition, Installation and utilization methods of CRP are presented as case studies based on the implementation items on CRP at each step.

《Basic concept of CRP installation》

	Step1	Step2	Step3	
Needs	Dropped objects and traffic congestion, etc.	Merging assistance in expressway	Intersection of local road	
Method＝	1 (Lane number counting) Identify the longitudinal location by using reference points installed at both end and specify lateral location by showing the lane number.		2 (Measuring distance) Identify detailed location by the relative location from reference point.	
Relative Accuracy of Information (σ)	several – 10 (or more) meters	1 - several meters	Approx. 25cm	
Implementation Items on CRP	(Issues of HD Maps)→		Determine requirements for mapping rules.	accuracy assurance
		Define how to install CRP.		common definitions
	Determine common names or IDs. (Issues regarding CRP)			common names

《CRP installation》

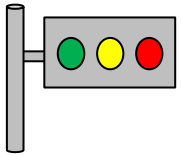
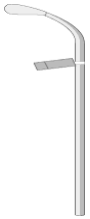
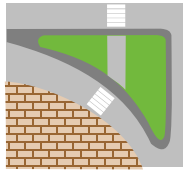
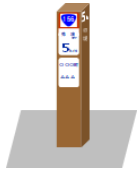
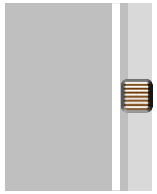
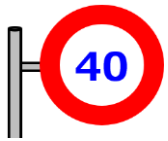
Case Study:
Road traffic information by lane

Case Study:
Merging assistance information

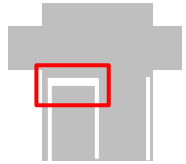
We hope in the future that concrete definition and maintenance methods will be determined considering the demonstration experiments based on the case studies.

(Appendix)

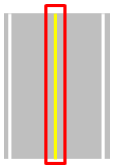
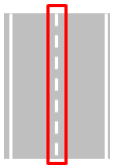
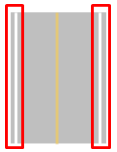
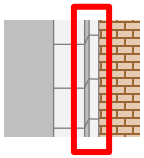
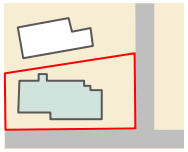
(Appendix) Candidates of AP Object

		Objects Name		Traffic Light	Road lighting pole	Refuge	Milestone marker / Road Reference Point	Catch Basin	Traffic Sign
Desk Study Results	1	**Public institution manages the object** (Applicable objects are extracted from laws, regulations, design standards, etc.)							
		Image							
		Overview							
	2	**Universally installed**	• Very universal • Somewhat universal • Not so universal	Somewhat universal	Somewhat universal	Not so universal	Somewhat universal	Very universal	Somewhat universal
	3	**The location does not change in real world**	• Likely to change • Less likely to change	Less likely to change	Likely to change	Less likely to change	Less likely to change	Less likely to change	Less likely to change
	4	**Easy to be measured by MMS**	• Easy to be measured • Difficult to be measured unless obstacles are removed • Difficult to be measured	Easy to be measured	Easy to be measured	Easy to be measured	Difficult to be measured unless obstacles are removed	Difficult to be measured	Easy to be measured

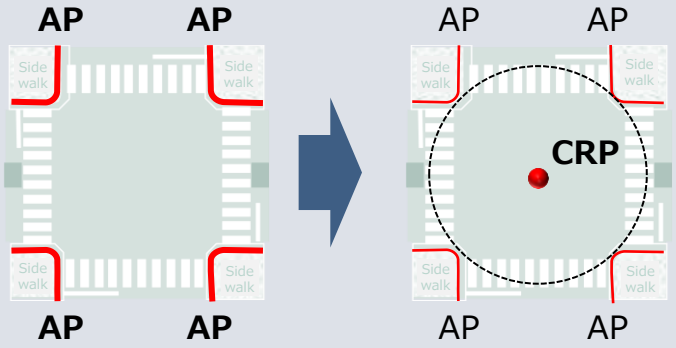
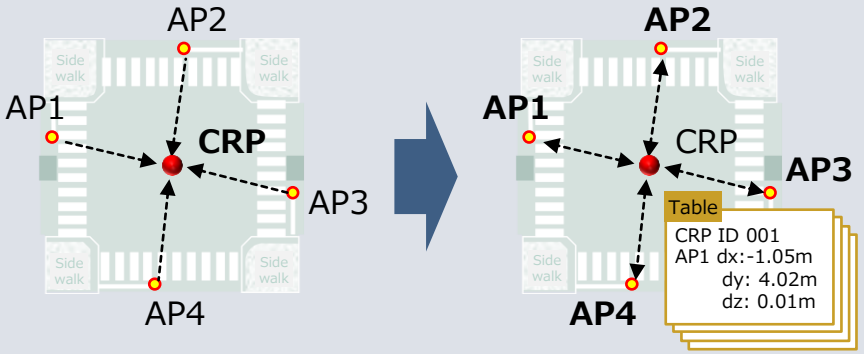
(Appendix) Candidates of AP Object (List)

		Objects Name		The bottom part of traffic light or traffic sign	Guide light	Pedestrian crossing guidance line (104)	-	Channelizing strip (107)
						Pedestrian crossing (201)	**Stop Line (203)**	**Approaching safety zone or obstacle on road (208) Channelizing strip (208-2)**
Desk Study Results	**1**	**Public institution manages the object** (Applicable objects are extracted from laws, regulations, design standards, etc.))						
		Image						
		Overview						
	2	**Universally installed**	• Very universal • Somewhat universal • Not so universal	Somewhat universal	Not so universal	Somewhat universal	Somewhat universal	Somewhat universal
	3	**The location does not change in real world**	• Likely to change • Less likely to change	Likely to change	Likely to change	Likely to change	Likely to change	Likely to change
	4	**Easy to be measured by MMS**	• Easy to be measured • Difficult to be measured unless obstacles are removed • Difficult to be measured	Difficult to be measured unless obstacles are removed	Easy to be measured	Easy to be measured	Easy to be measured	Easy to be measured

(Appendix) Candidates of AP Object (List)

				Center line of lane (101)	Lane Boundary (102)	Outside line of lane (103)	Road Boundary	Guardrail, Fence	Border between Government Land and Private Land	"Road Edge" on Funda-mental Geospatial Data
		Objects Name		Center line (105)	Lane Boundary (206) Vehicle traffic zone (109)	Side strip (108-4)				
Desk Study Results	1	**Public institution manages the object** (Applicable objects are extracted from laws, regulations, design standards, etc.)								
		Image								
		Overview							Demarcated public-private boundary	Road zone defined by Road Act
	2	**Universally installed**	• Very universal • Somewhat universal • Not so universal	Somewhat universal	Somewhat universal	Somewhat universal	Very universal	Not so universal	Very universal	Very universal
	3	**The location does not change in real world**	• Likely to change • Less likely to change	Likely to change	Likely to change	Likely to change	Likely to change	Likely to change	Less likely to change	Less likely to change
	4	**Easy to be measured by MMS**	• Easy to be measured • Difficult to be measured unless obstacles are removed • Difficult to be measured	Easy to be measured	Easy to be measured	Easy to be measured	Easy to be measured	Easy to be measured	Difficult to be measured	Difficult to be measured

(Appendix) Method of Installing CRP

	Installation based on the rule (Method #1)	Installation based on the table (Method #2)
Outline	1. Decide the AP location 2. Automatically calculate CRP from AP ⇒ Each map sets AP & CRP based on the rule  1. Each map confirms the AP location. (e.g. Road Boundary) 2. Each map automatically calculates CRP from AP based on the rule. (e.g. center of inscribed circle)	1. CRP is set up by an initial installer 2. Set up a table for relative coordinate of CRP & AP ⇒ Each map sets AP and CRP based on the table ※It is necessary to maintain not only the table but also the map itself as reference, depending on the type of AP object,  1. An initial installer automatically calculates CRP from AP based on the rule. (e.g. weighted average of AP) 2. Set up a table for relative coordinate of CRP and all AP.
Advan-tage/ disad-vantage	(+) Low cost of managing CRP (+) Operation is easier; even if AP moves, only CRP on each map needs to be updated based on the rule (-) If AP is the object likely to change its location, CRP will be also likely to change (-) The rule which are applicable to any location is necessary	(+) Even if AP moves, CRP does not move (+) LO can be set as (a part of) AP (-) The initial installer of table is necessary, which requires the cost for managing tables (-) The management of AP on the table is necessary (e.g. recording which traffic light is used as AP, updating the location of AP after AP moved)

※It is possible to combine Method #1 and Method #2 when setting up CRP.