

# Truck Platooning

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Mechatronic System Engineering Project

Guided by Prof. Dr. Stefan Henkler

Summer 2021

Team 1

# Agenda

1. Motivation
2. CONSENS Method
3. Software Model
4. Cognitive Operator
5. Implementation
6. Learning Outcomes

# 1. Motivation

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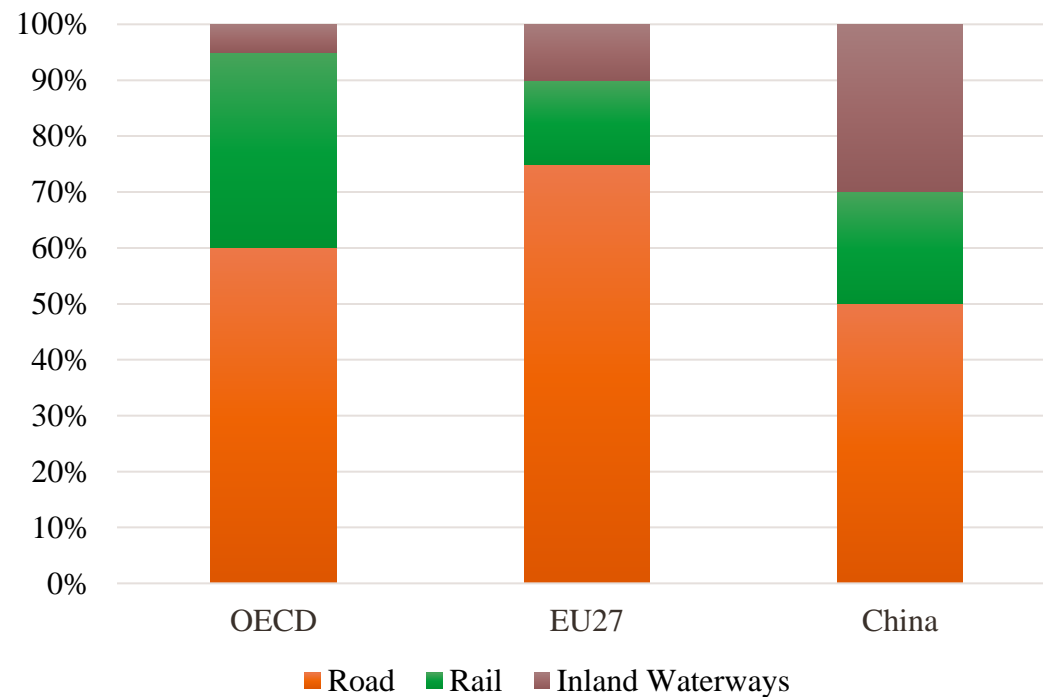
Problem



Solution

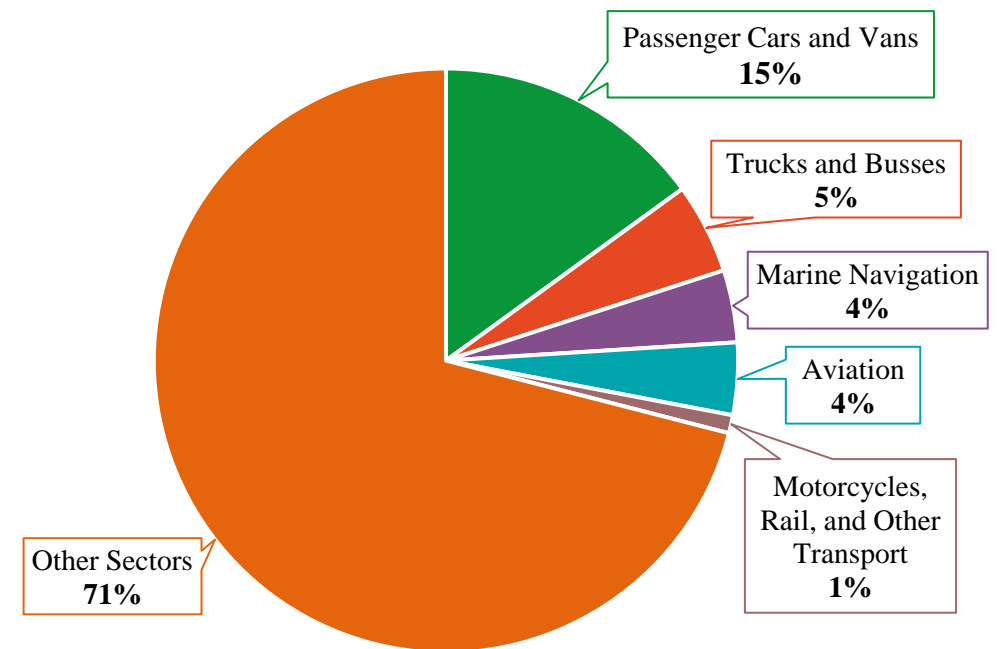
# Problem

## Surface Freight Transport Volumes



Source: OECD/ITF. ITF Transport Outlook 2017. Technical report, OECD, 2017

## Greengrass Gas Emission in the EU 2018



Source: icct

# Solution

## Potential Benefits

Fuel economy due to  
reduced air resistance

Shorter commutes during  
peak periods.

On longer highway trips,  
vehicles are unattended  
whilst in following mode.

Fewer traffic collisions.

## Potential Disadvantages

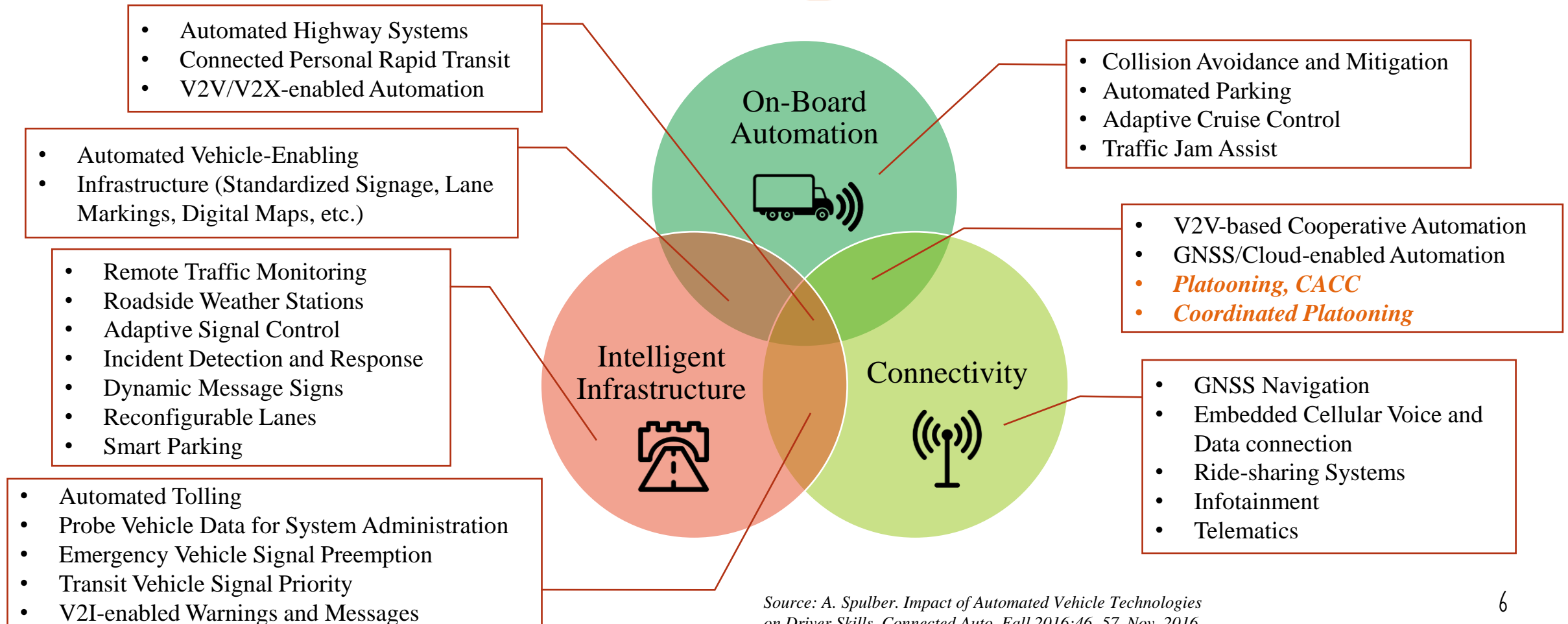
Some systems have  
failed due to remote  
computer hacking.

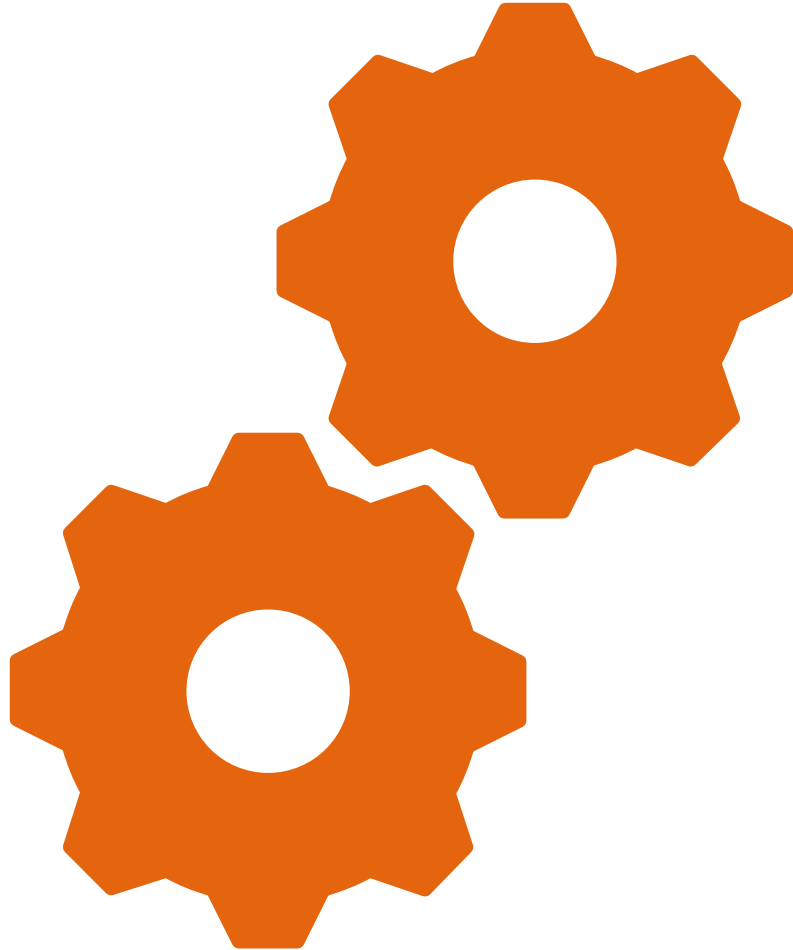
**Platooning**

Truck Platooning



# Information and Communication Technology in Transportation Systems



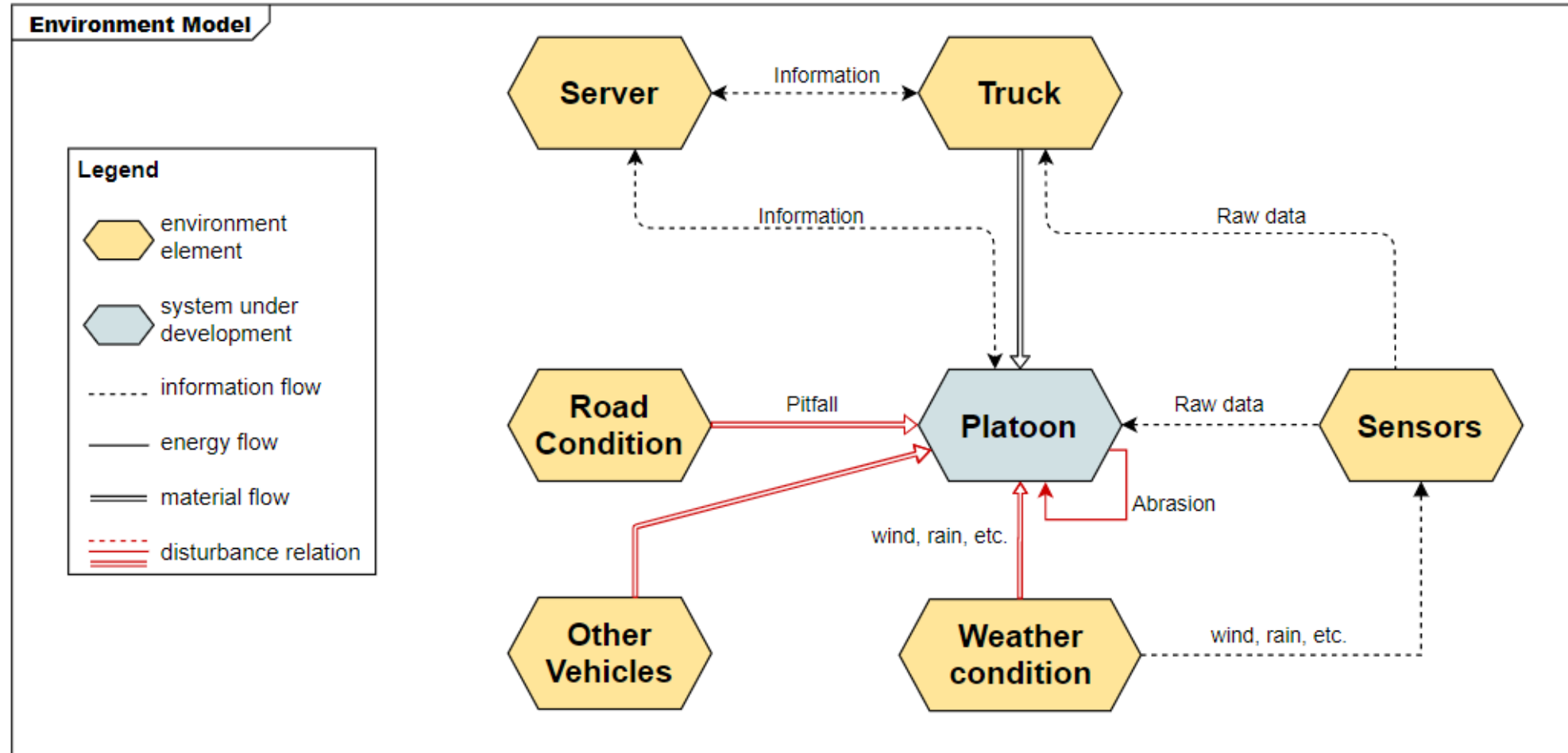


## 2. CONSENS Method

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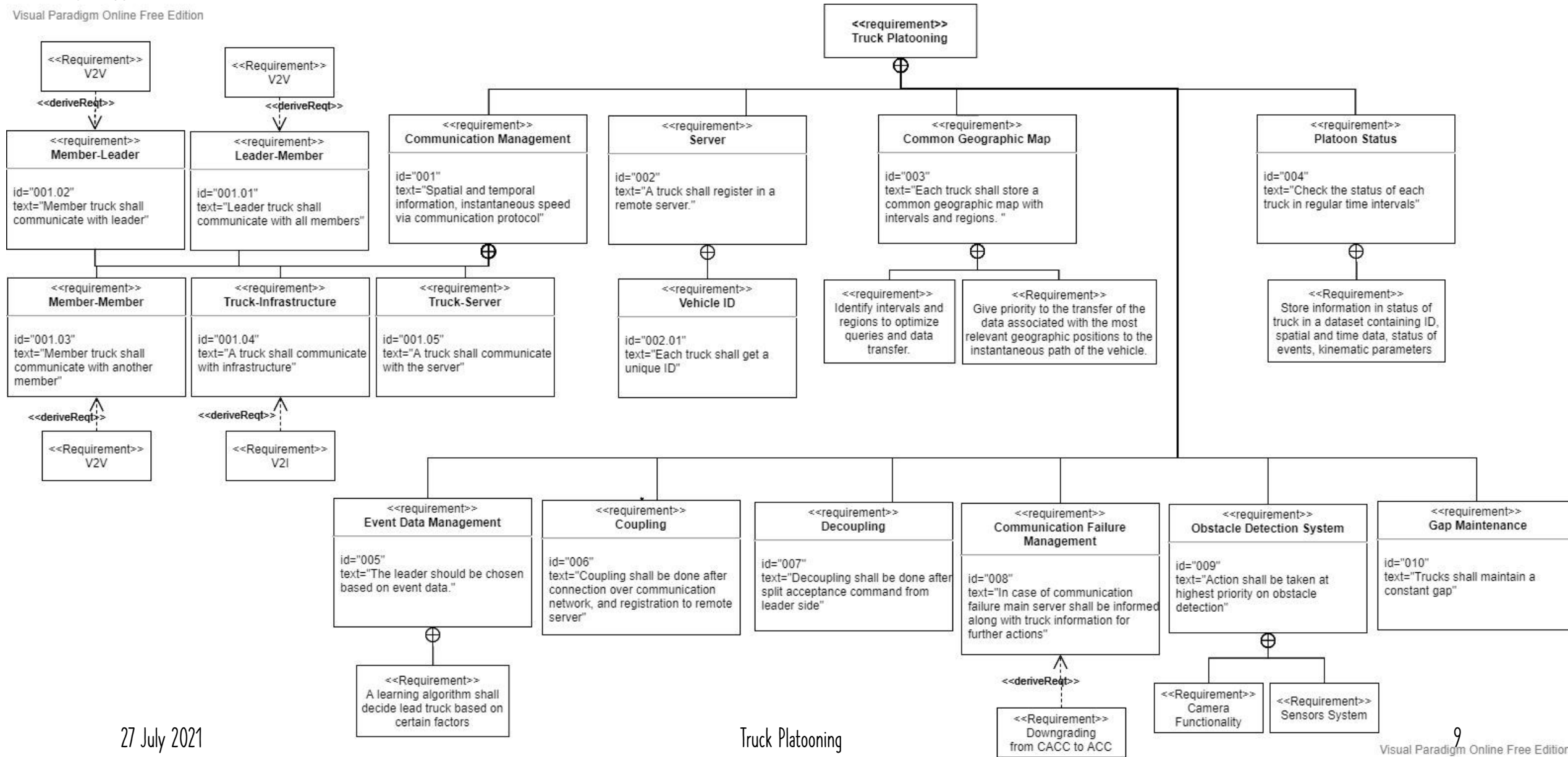
- Environment Model
- Requirement
- Functions
- Active Structure
- Application Scenario

# Environment Model

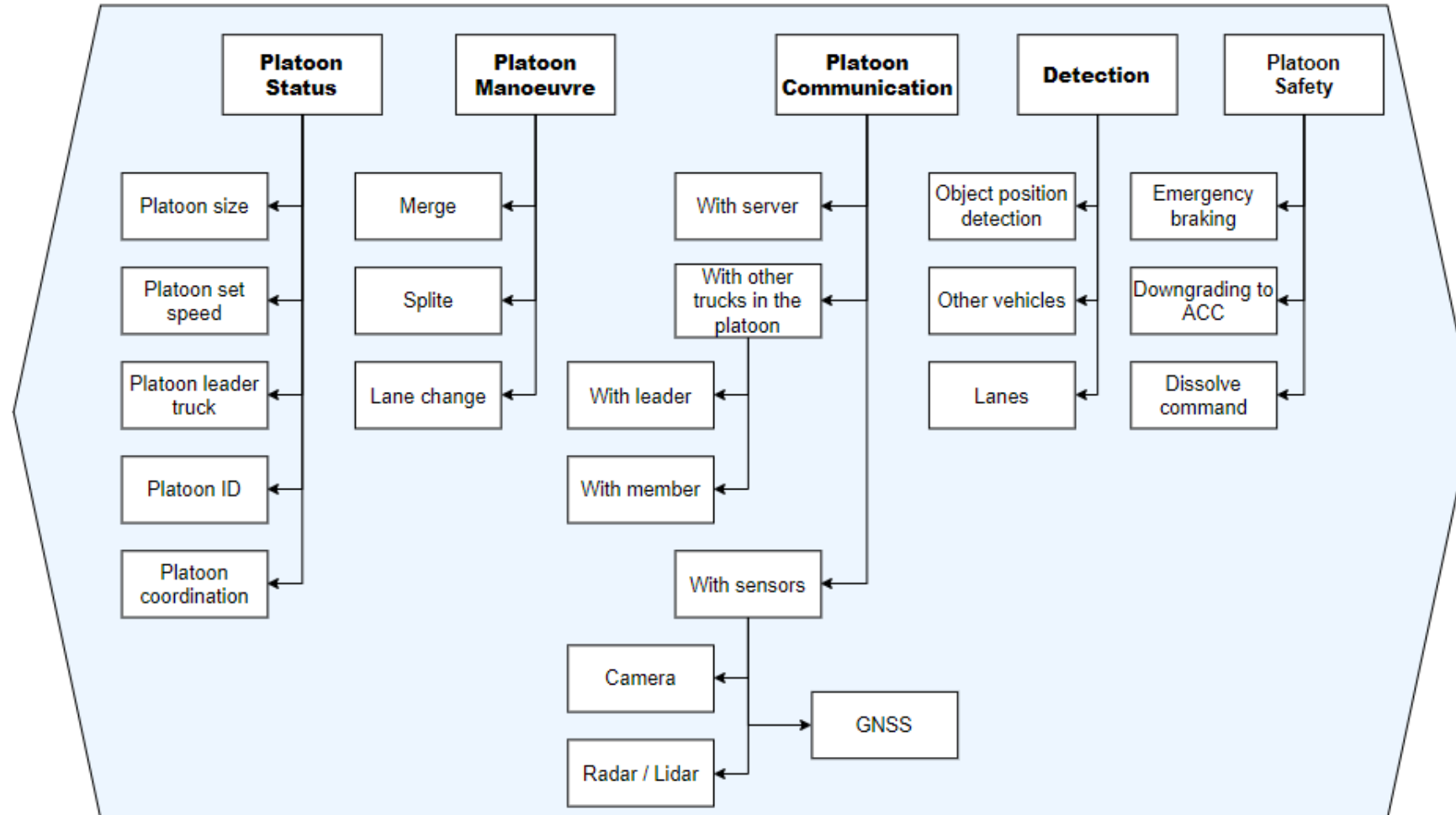




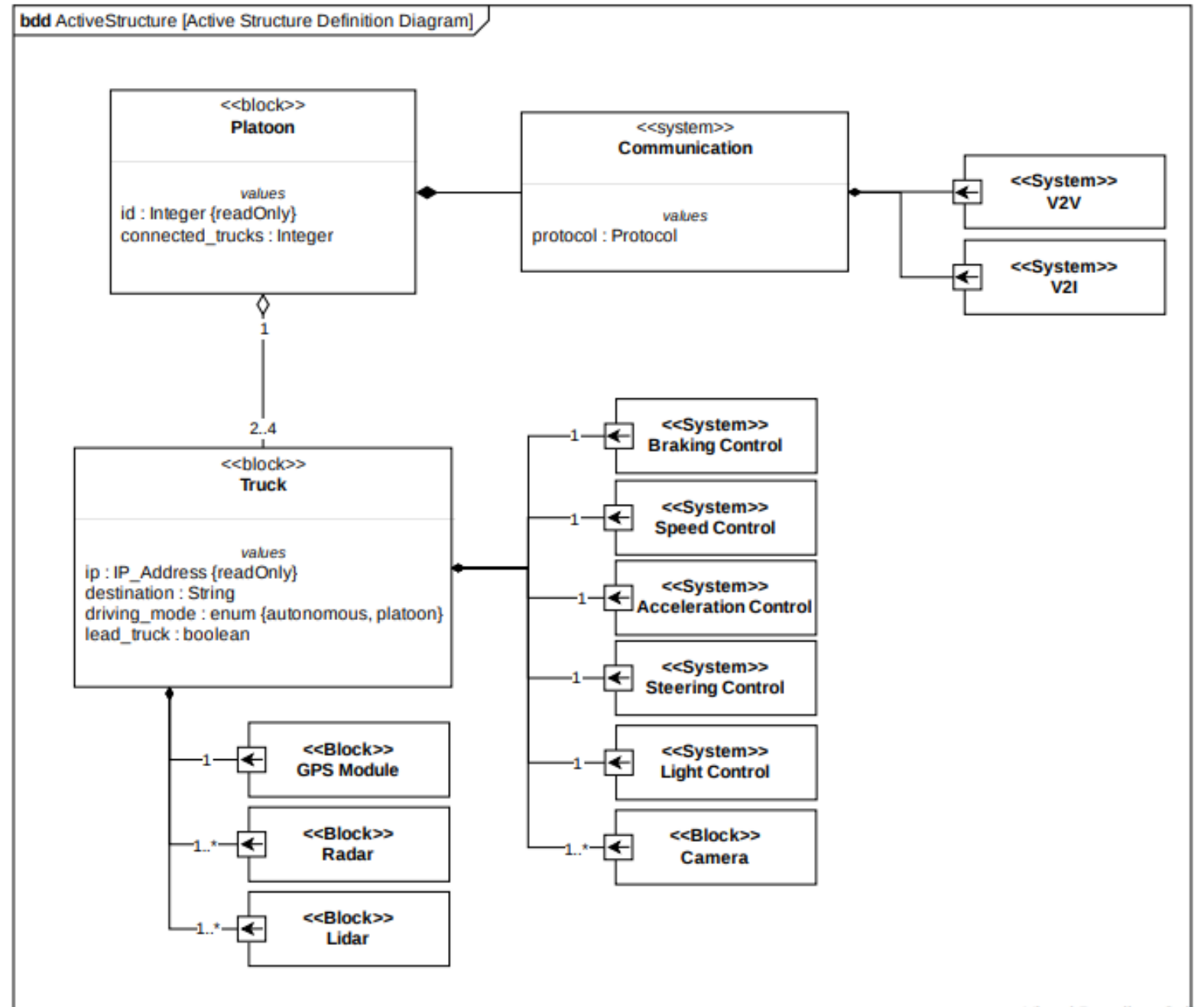
# Requirement



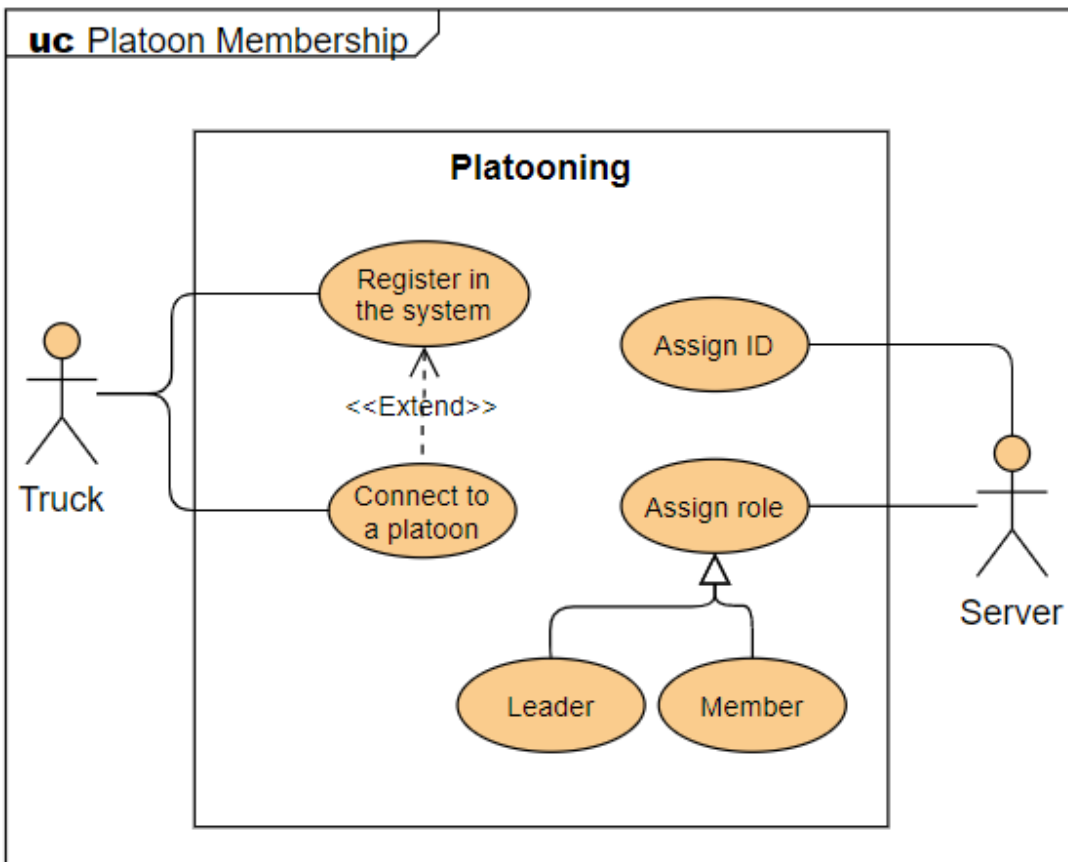
# Function Hierarchy



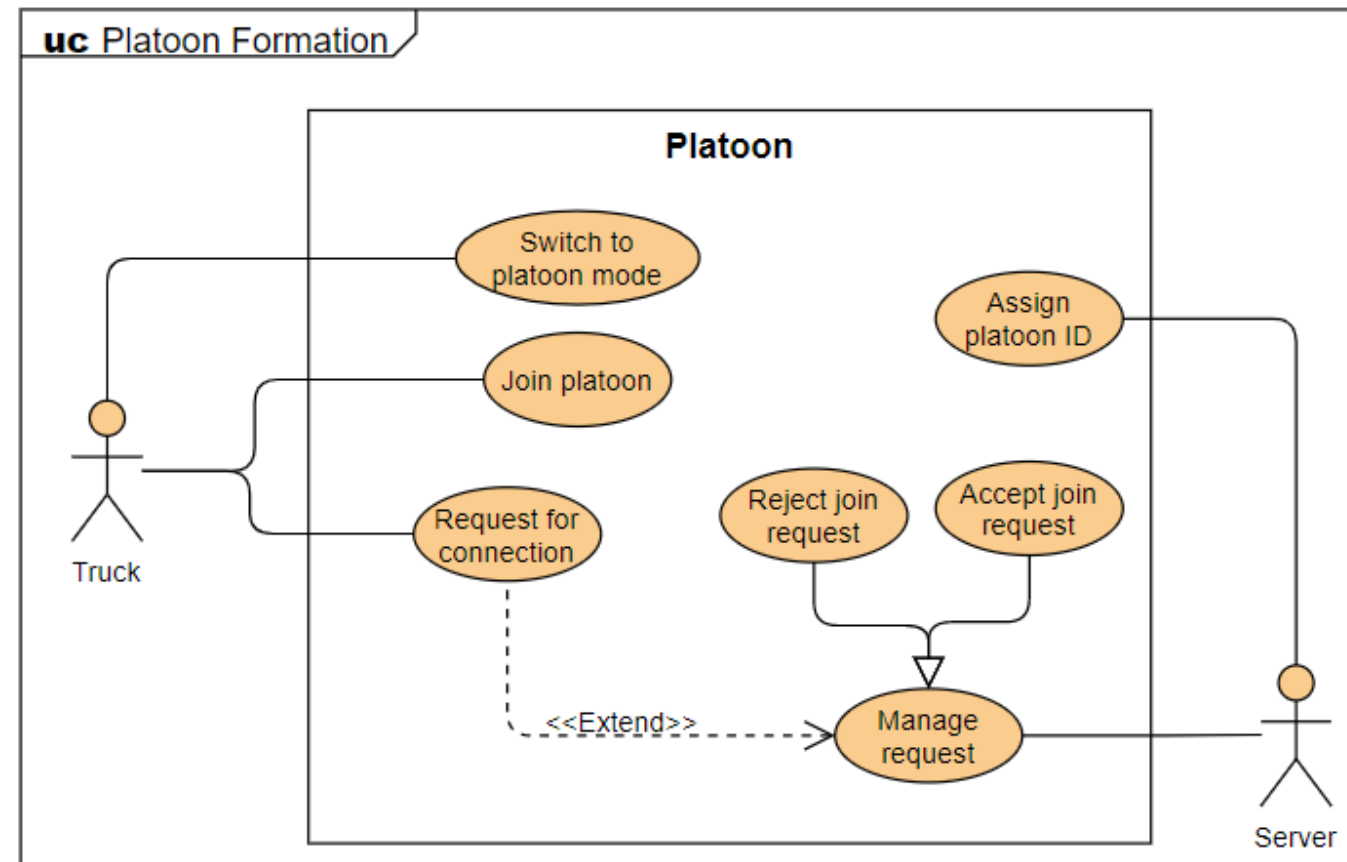
# Active Structure



# Application Scenario



27 July 2021



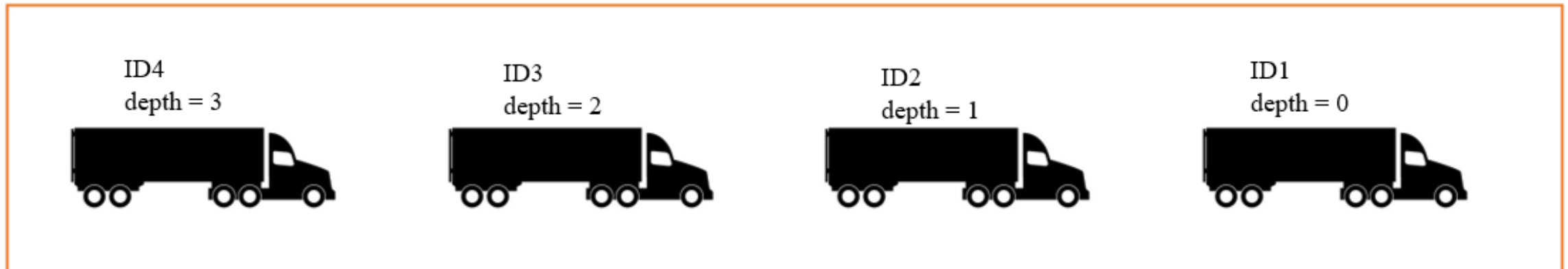
Truck Platooning

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# Variables

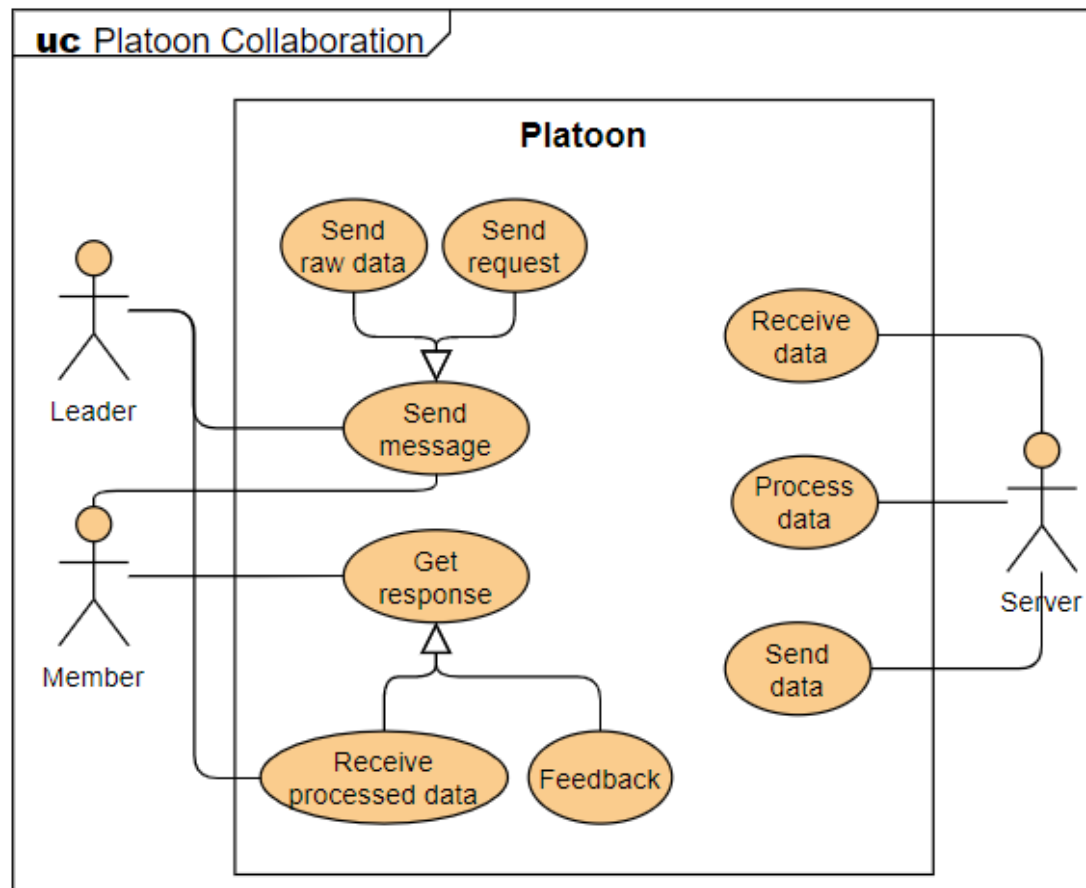
## Variables are assigned by registration

- Vehicle ID: unique string → Static
- Platoon ID: unique string → Static
- Platoon size:  $> 1 \ \&\& \ < 5$  → Dynamic
- Platoon depth:  $> 0$  → Dynamic
- Platoon members: all vehicle IDs in a platoon → Dynamic

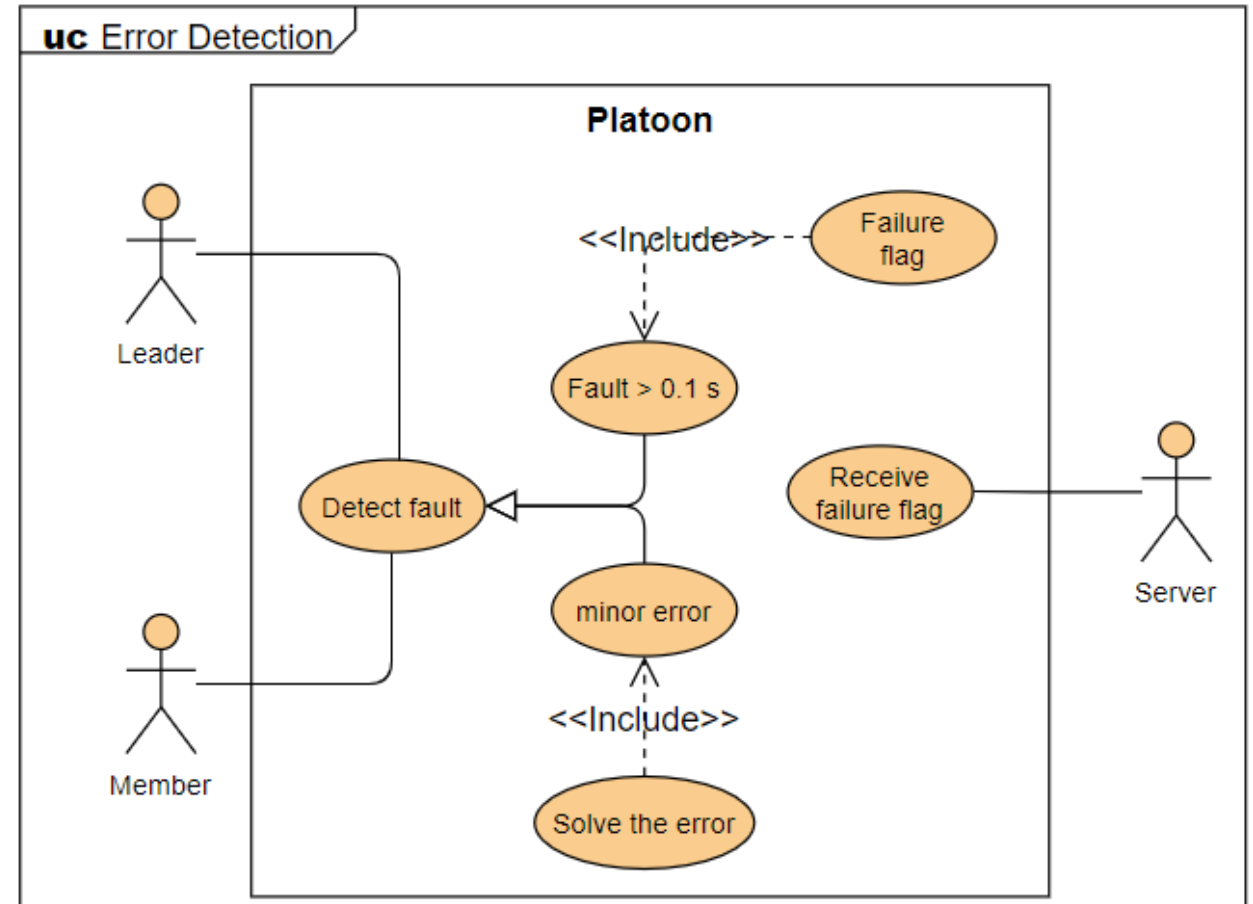


**ID**  
**size = 4**  
**member = ID1, ID2, ID3, ID4**

# Application Scenario



27 July 2021



Truck Platooning

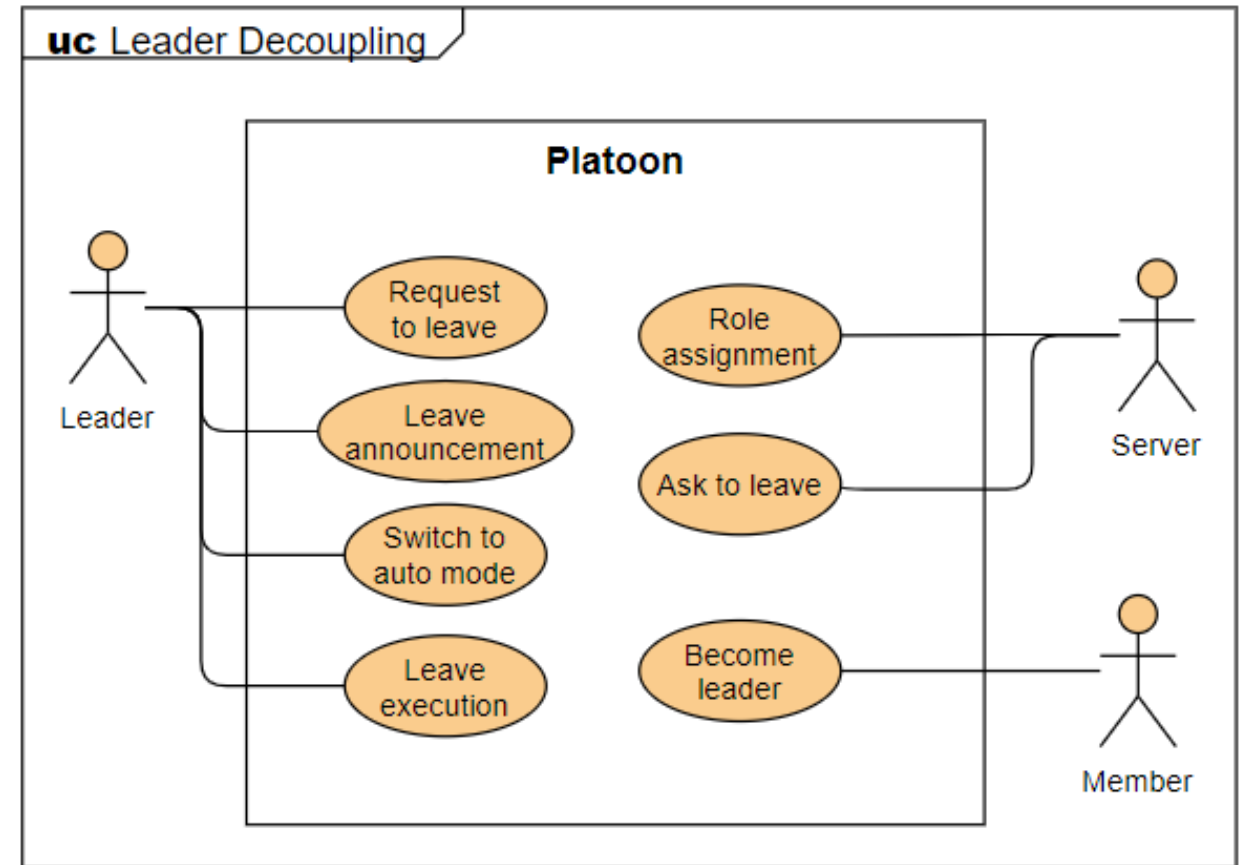
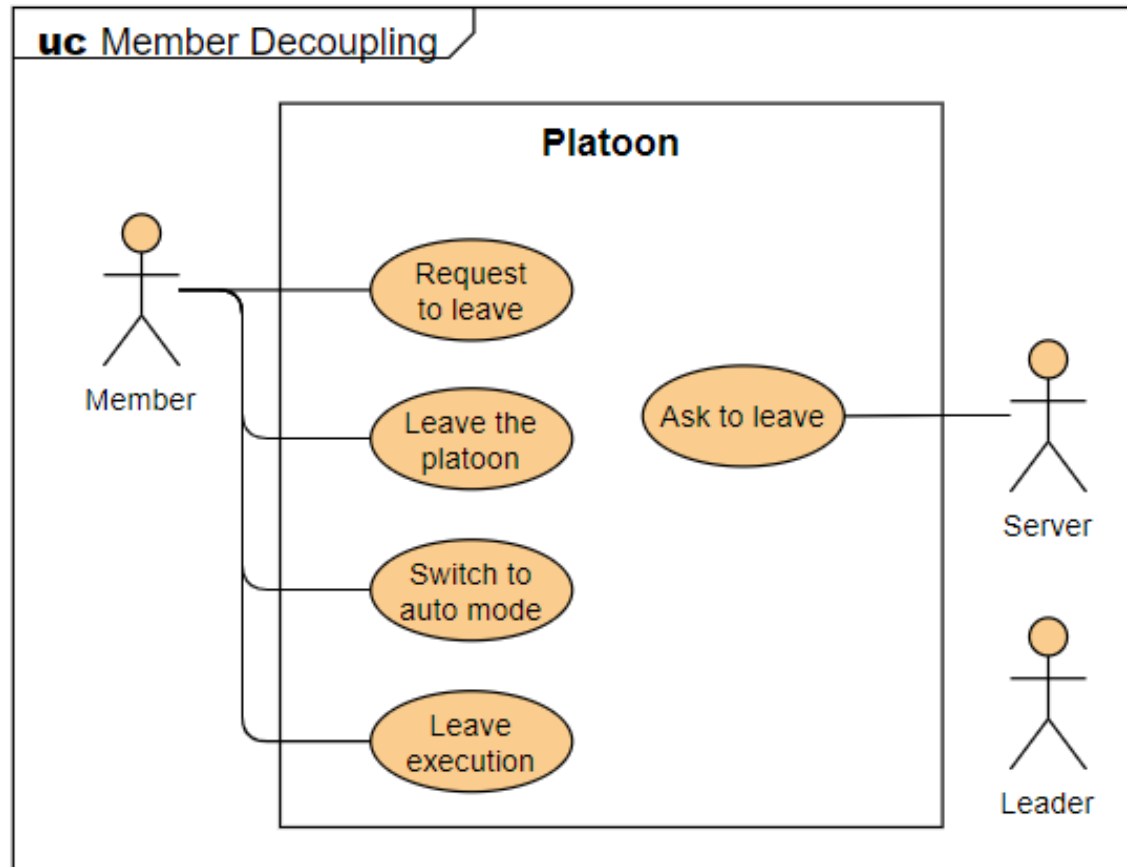
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# Communication Failures

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- Effect of communication failure on CACC controller: Failure to receive data for 0.1s generates the communication failure flag in CACC controller.
  - Downgrading from CACC to ACC is a solution.
- The leader wants to leave but due to communication failure, no response is received from followers to take over the platoon leader role.
  - As a result, the platoon leader breaks-up the platoon by using a DISSOLVE command.

# Application Scenario





# Scenarios

## Leader leaves the platoon:

1. Leave announcement: assign leader role to the second vehicle
2. Leave execution: Split + Lane Change + Merge

## Follower leaves the platoon:

1. Leave request/response
2. Leave execution: Split + Lane Change + Merge

# 3. Software Model

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- MUML Techniques
- Architecture
- Communication
- Behavior



# MUML Techniques

## Modeling of the Structure

- Component Diagram

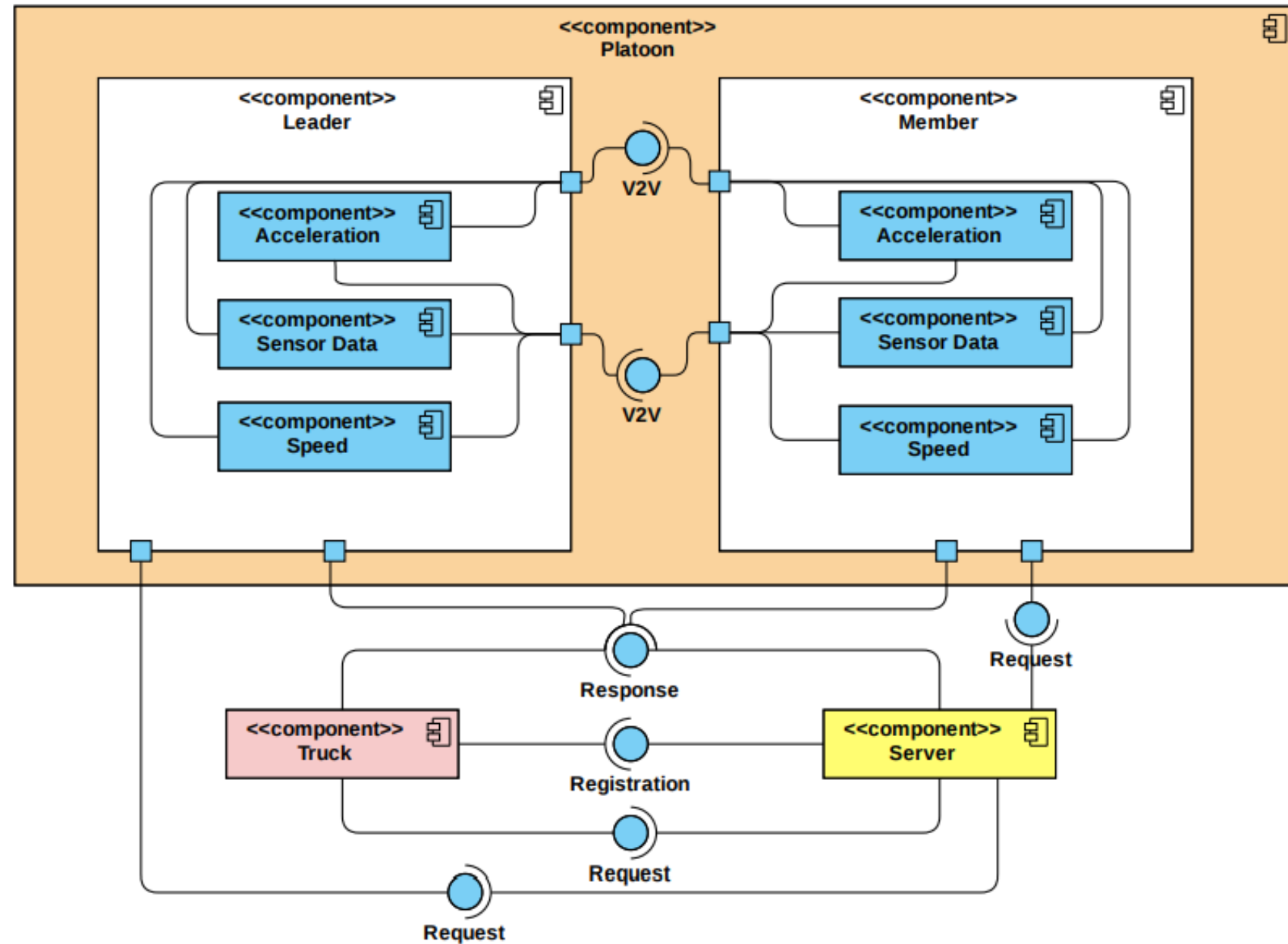
## Modeling of the Behavior

- Real-Time State-charts

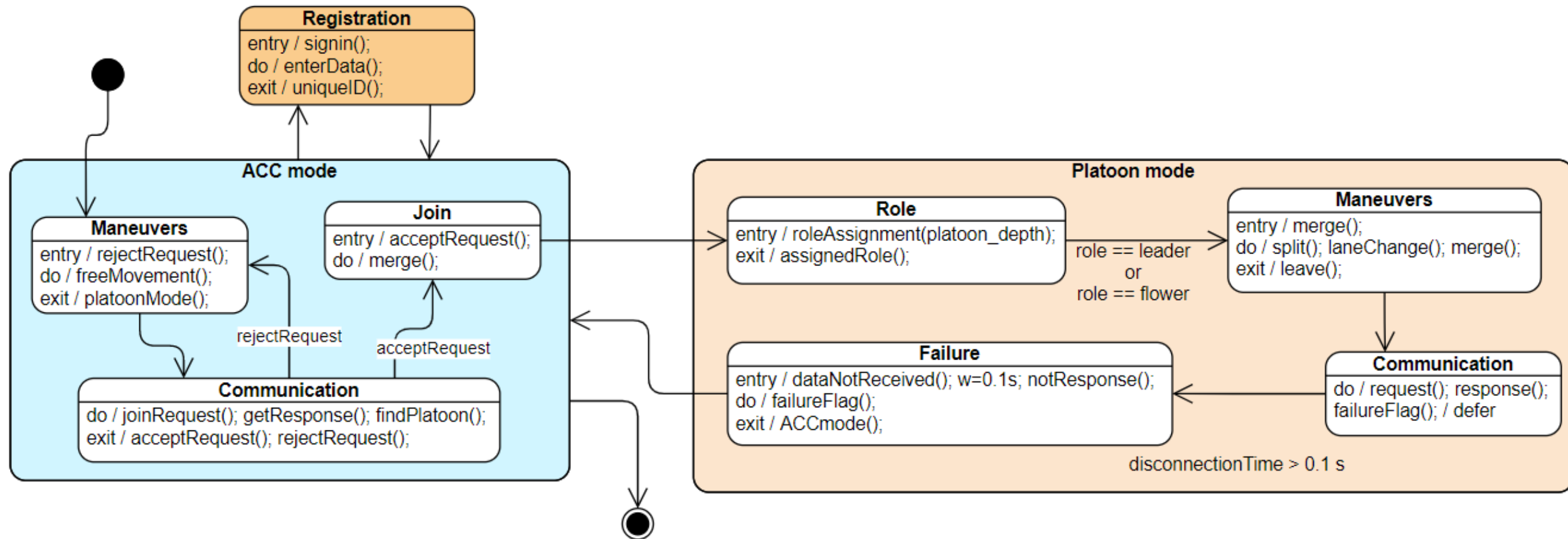
## Formal Verification

- UPPAAL

# Component Diagram

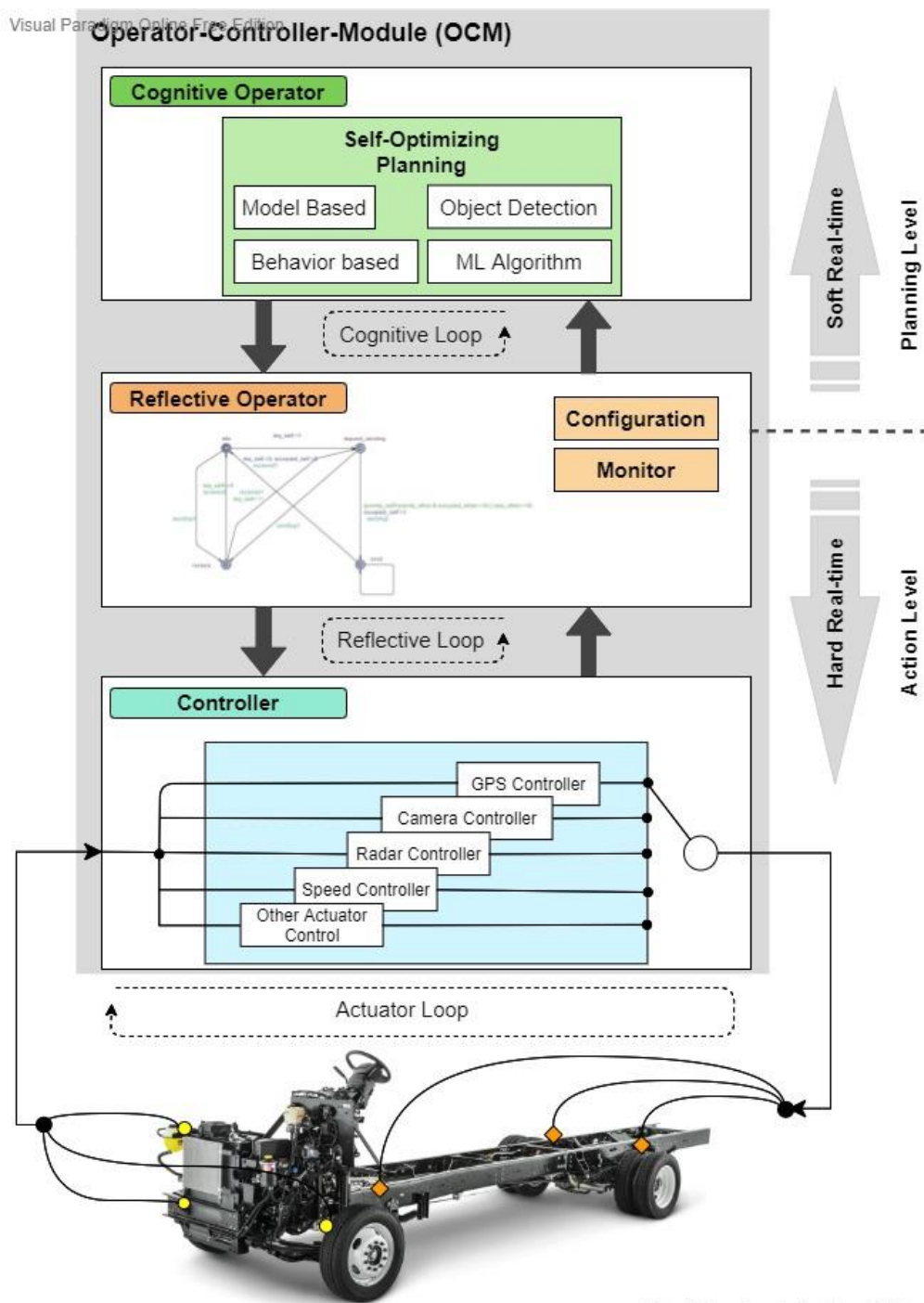


# Real-Time State-Charts

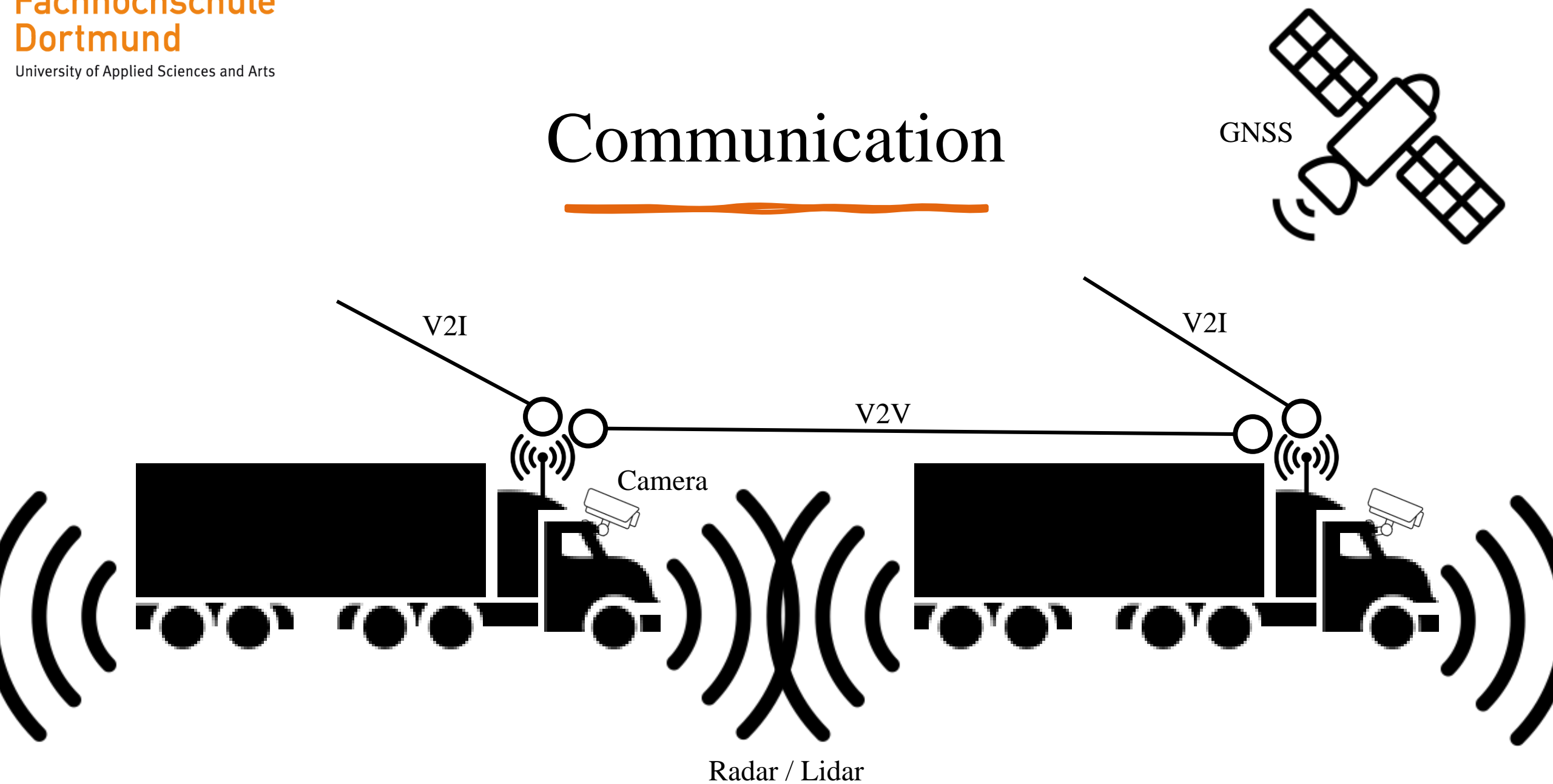


# Architecture

## OCM Model



# Communication



# Micro- Commands

Micro-Commands used in platoon management protocol.

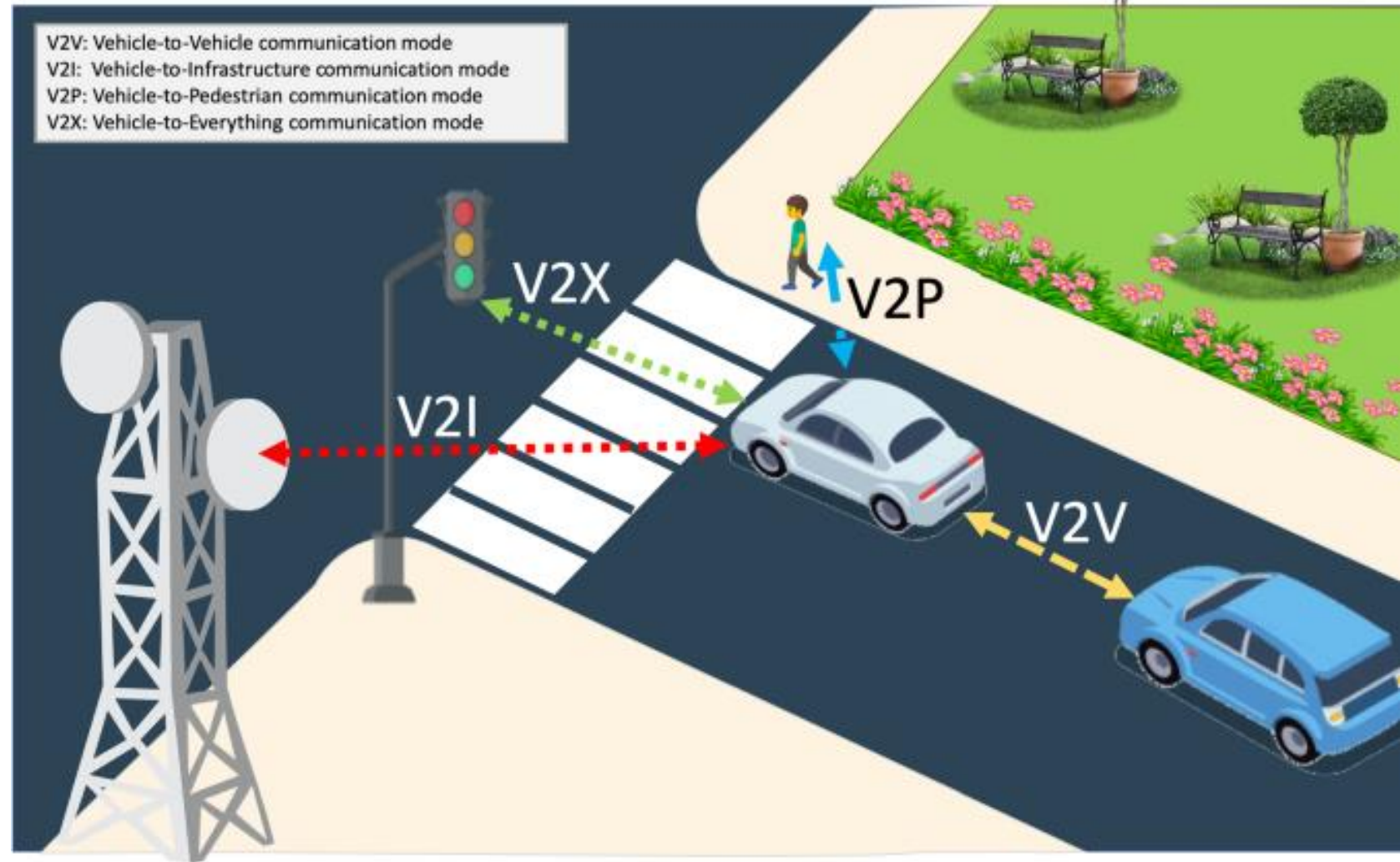
U: Unicast, M: Multicast, B: Broadcast

	Micro-command	Description	Sender / Receiver
1	MERGE_REQ (U)	Asking to merge into a platoon	A vehicle in ACC mode to a platoon leader
2	MERGE_ACCEPT (U)	Accepting merge request	The platoon leader in reply to MERGE_REQ
3	MERGE_REJECT (U)	Rejecting merge request	The platoon leader in reply to MERGE_REQ
4	MERGE_DONE (U)	Notifying the merge completion	Old vehicle in ACC mode to the platoon leader
5	SPLIT_REQ (U)	Split the platoon into two parts	Platoon leader to a member
6	SPLIT_ACCEPT (U)	Accepting split request	Member to the platoon leader in reply to SPLIT_REQ
7	SPLIT_REJECT (U)	Rejecting split request	Member to the platoon leader in reply to SPLIT_REQ
8	SPLIT_DONE (U)	Notifying the split completion	Member to the platoon leader
9	LEAVE_REQ (U)	Member, asking to leave the platoon	Member to the platoon leader
10	LEAVE_ACCEPT (U)	Accepting leave request	Platoon leader to the member in reply to LEAVE_REQ
11	LEAVE_REJECT (U)	Rejecting leave request	Platoon leader to the member in reply to LEAVE_REQ
12	NEW_LEADER (U)	Assigning a new leader role	Current platoon leader to the second member
13	DISSOLVE (M)	Accepting the new platoon leader role	The second member to the current platoon leader
14	CHANGE_PL (U or M)	Announcing the new platoon leader	Current platoon leader to all its members
15	ACK (U)	Acknowledging the message reception	The receiving entity to the sending entity



# Protocol

- V2X
  - V2V
  - V2I
  - V2P

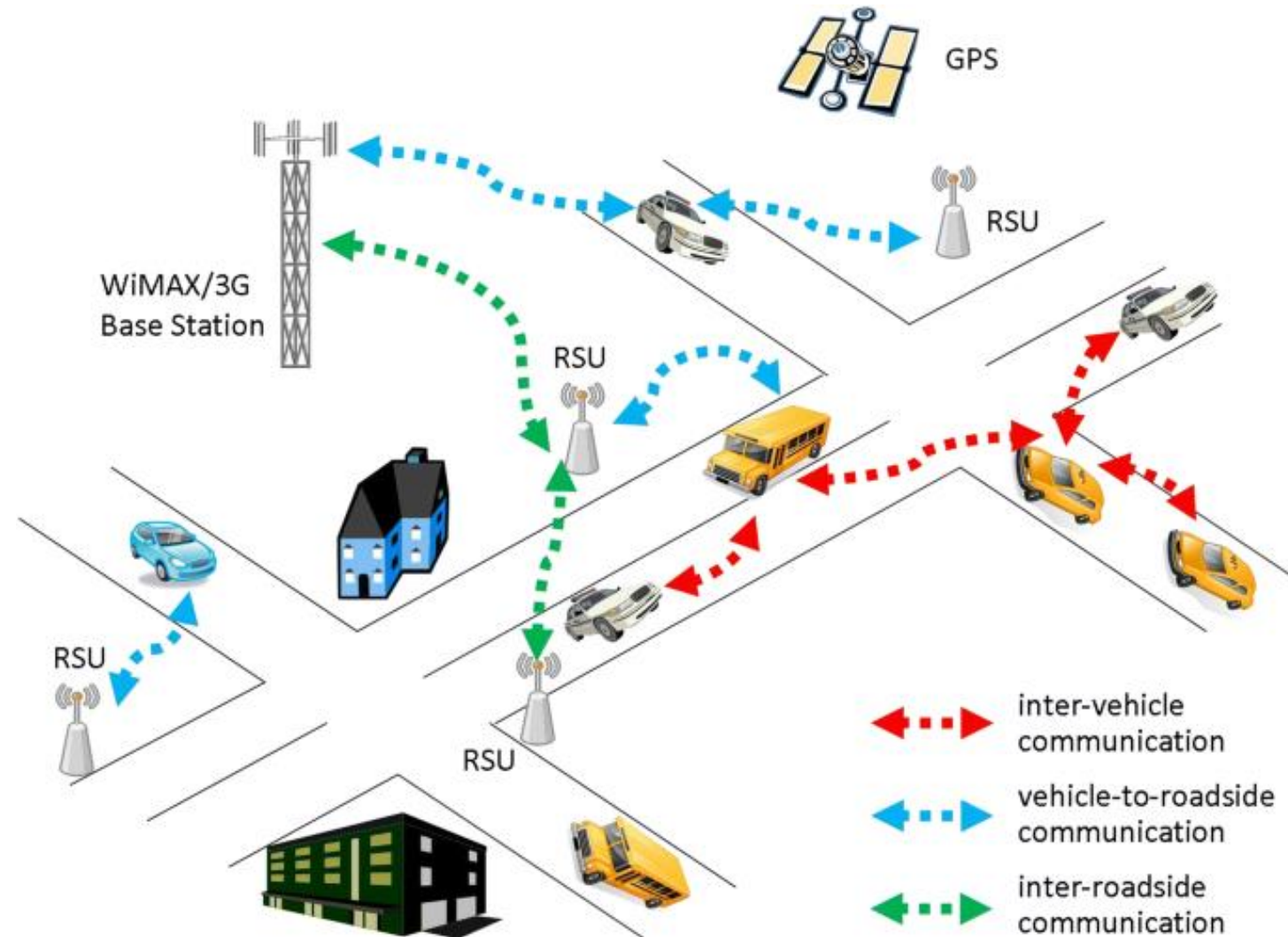


*Source: A tutorial survey on vehicle-to-vehicle communications*

# Protocol

- VANET

Vehicular ad hoc networks



*Source: A tutorial survey on vehicle-to-vehicle communications*

# Control Behavior

- Maneuvers are coordinated by a structured exchange of messages among relevant neighboring vehicles or Road-Side Units (RSUs).
- Can happen at any points, only allow one maneuver at a time.
  - **Merge:** Merge request + Merge response + Merge execution
  - **Split:** Split request + Split response + Split execution
  - **Lane change**

All complex maneuvers are the combinations of these three.

# Cognitive Operator

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## Clustering Algorithm

- Unlabeled dataset of 30 trucks.
- k-means based on maximum match of route and speed profile.
- Formed clusters as platoons.
- Assigned leader role to truck nearest to centroid in each cluster and follower role to others.

# Cognitive Operator

	TruckID	Distance of route	Max.match of route	Consumption	Equipment Sensors	Speed Profile
0	1	500	40	medium	Radar	3
1	2	400	30	low	Radar	4
2	3	310	20	low	Radar Camera	5
3	4	250	10	low	Radar Camera	4
4	5	600	35	high	Radar	2
5	6	1000	50	high	Radar Lidar	3
6	7	300	20	medium	Radar Camera	4
7	8	450	40	low	NaN	5
8	9	800	45	low	Radar Camera	5
9	10	700	40	low	Radar Camera	5
10	11	500	35	medium	Radar	4
11	12	400	27	high	Radar Camera	3
12	13	550	32	medium	Radar Camera	4
13	14	650	37	medium	Radar Lidar	4
14	15	750	30	medium	Radar Camera	3
15	16	1000	40	medium	Radar	3

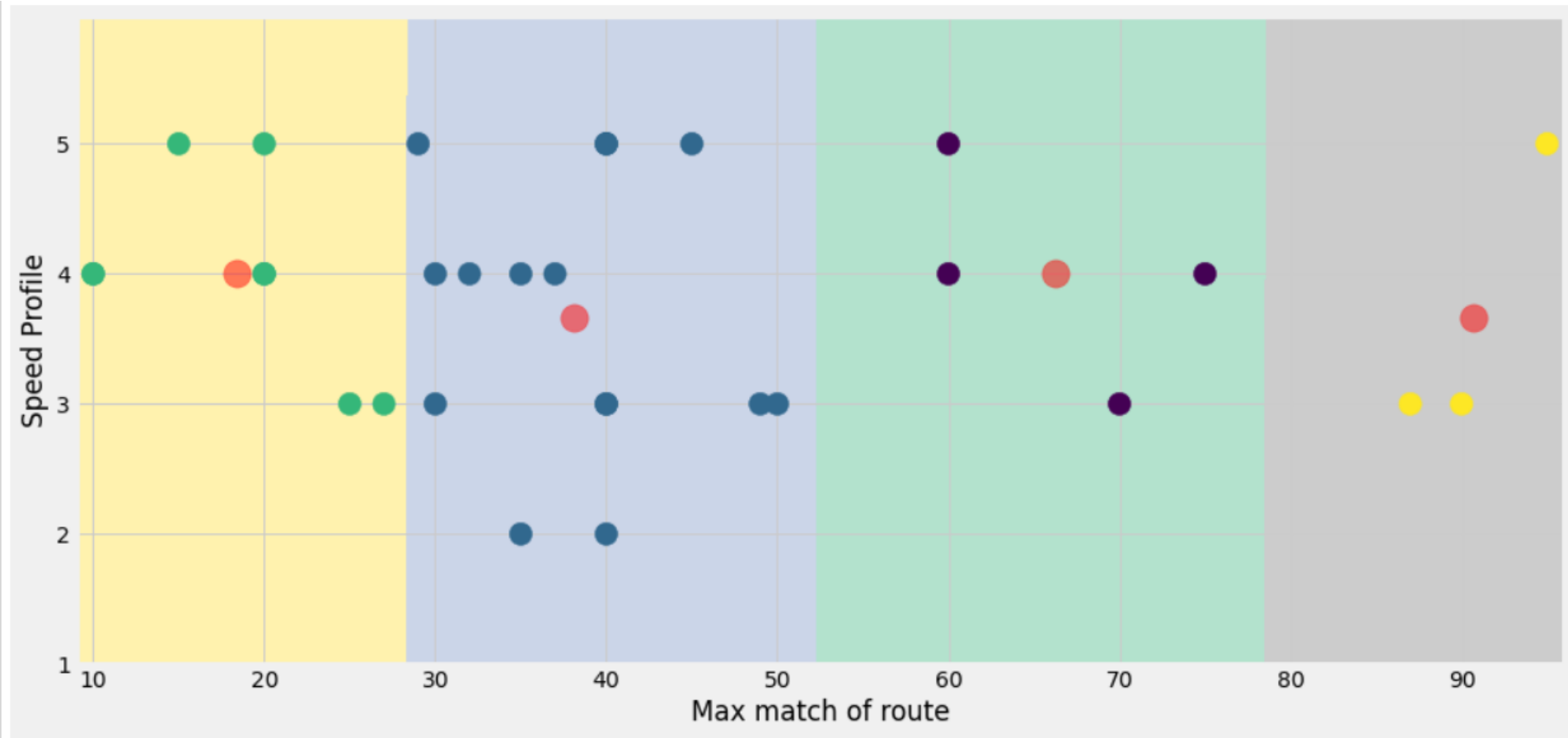
Initial Dataset

# Cognitive Operator

TruckID	Distance of route	Max.match of route	Consumption	Equipment	Sensors	Speed Profile	Platoon ID	IsLeader
0	1	500	40	medium	Radar	3	1	1
1	2	400	30	low	Radar	4	2	0
2	3	310	20	low	Radar Camera	5	2	0
3	4	250	10	low	Radar Camera	4	2	0
4	5	600	35	high	Radar	2	1	0
5	6	1000	50	high	Radar Lidar	3	0	0
6	7	300	20	medium	Radar Camera	4	2	0
7	8	450	40	low	NaN	5	1	0
8	9	800	45	low	Radar Camera	5	3	0
9	10	700	40	low	Radar Camera	5	3	1
10	11	500	35	medium	Radar	4	1	0
11	12	400	27	high	Radar Camera	3	2	0
12	13	550	32	medium	Radar Camera	4	1	0
13	14	650	37	medium	Radar Lidar	4	3	0
14	15	750	30	medium	Radar Camera	3	3	0
15	16	1000	40	medium	Radar	3	0	0

Results in IsLeader column after applied algorithm.

# Cognitive Operator





# State Modeling and Verification

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UPPAAL



# Implementation

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Carla

# Learning Outcomes

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We were able to:

- adopt CONSENS Method.
- make a software model by MUML Techniques, architecture, communication and behavioral modeling.
- model through UPPAAL.
- implement Machine Learning algorithm.
- simulate through Carla.
- code in Python.



# TEAM 1

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THANK  
YOU