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Interoperable GCDC AutoMation Experience

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Executive Summary

The scenarios for the competitions and demonstrations in i-GAME, act as input to all other work packages (WP) and have impact on required technology, communication standards, evaluation criteria as well as the overall contribution of the project to future progress towards realization of cooperative traffic systems in a live environment.

The scenarios are specified such that they will encourage teams with varying resources and technology to participate. They highlight situations where transitions between automated and manual driving are required as well as mixed-traffic situations where cooperative vehicles interact with non-cooperative vehicles.

The scenario descriptions will provide guidelines to the participating teams, and to other deliverables that elaborate the vehicle performance requirements (e.g. automatic steering), interaction requirements (e.g. reliable data), safety requirements (e.g. fault tolerance) and judging/evaluation requirements (e.g. evaluation of the scenario).

Cooperative vehicles (CVs) can, better than autonomous and manually driven vehicles, resolve complex traffic situations with regards to safety, traffic flow and energy efficiency. The scenarios have been selected with the intention to demonstrate scenarios where collaboration is an advantage.

One of the major drivers for i-GAME and the GCDC 2016 is to promote a gradual and realistic introduction of automated vehicles in real traffic situations in the near future. Vehicles with the ability to adapt to various degrees and modes of automation in different situations are the ones most likely to succeed - the survival of the fittest.

Potential participating teams, having signed a letter of intent at the time of the application, have been invited to suggest scenarios through an on-line survey. The results have been analysed by the project partners and this has resulted in the following three scenarios:

1) Cooperation on Highway

   Two platoons in different lanes on a highway receive a message from a construction site ahead. The vehicles must negotiate to form one single platoon before the site. This has to be performed with a minimum loss of speed and a maximum of safety and comfort to the passengers

2) Cooperative Intersection

   One vehicle is approaching a busy main road without traffic control. It intends to do a left turn onto the road and cooperates with approaching vehicles on the main road to allow a safe and comfortable passage onto the road

3) Emergency Vehicle (demonstration)

   An emergency vehicle is approaching a condensed traffic situation from behind. It communicates the intention to pass the vehicles and in which position on the road it prefers to have a free passage. The vehicles collaborate to allow free passage for the emergency vehicle

These scenarios are motivated as follows. First, they focus on realistic traffic situations that regularly occur in everyday traffic. Second, these scenarios contain basic manoeuvres (opening a gap, merging, lane changing, prioritising) that can be regarded as “building blocks” for a large set of possible traffic scenarios. Thirdly, these particular scenarios are rather challenging for the teams on the one hand, but also realistic goals on the other hand.

Evaluations will be performed on individual vehicle performance as well as on group (platoon) performance.

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1 Introduction

The i-GAME project

The objective of i-GAME is to develop technologies that speed-up the real-life implementation of automated driving, which is supported by communication between the vehicles and between vehicles and roadside equipment.

Scenarios in i-GAME

The scenarios for the competitions and demonstrations in i-GAME, act as input to all other Work Packages and have impact on required technology, communication standards, evaluation criteria as well as the overall contribution of the project to future progress towards realization of cooperative traffic systems in a live environment.

Background to selection of scenarios

One of the major drivers for i-GAME and the GCDC 2016 is to promote a gradual and realistic introduction of automated vehicles in real traffic situations in the near future. This approach has the following implications:

1) It is not necessarily the most expensive and sophisticated solution that solves the issues of a soon to come introduction of automated vehicles, especially if it relies on the same level of precision from other vehicles
2) Automated vehicles will have a wide range of capabilities during a foreseeable future as OEMs tend to look for unique selling points and a single vendor approach

Trucks and cars are both allowed in i-GAME. Basic platooning capabilities are mandatory to participate in the competition. This includes on an overall level:

- Ability to communicate (V2V) position, speed, acceleration to other vehicles
- Ability to adapt ego performance to signals from other vehicles in a platoon
- Ability to open up gaps allowing other vehicles to join the platoon from the side
- Ability to drive in an automated mode regarding longitudinal control. Lateral control is desired, and may be an advantage, but is not required

More details on vehicle performance and requirements will be available in coming deliverables (D1.2 Requirements – including Vehicle performance, Interaction requirements, Safety requirements and Evaluation requirements).

As the intention of GCDC 2016 is to allow a multitude of technologies to meet and perform cooperative driving manoeuvres with technology available “off the shelf”, the organizers will not always encourage the most sophisticated (i.e. most expensive) technology available. Instead the ambition is to allow a range of technology levels to work together alongside each other. The competition is about collaboration and adaptation. Cost efficient performance may be an evaluation criteria but this has not been decided at this time.

Vehicles with the ability to adapt to various kinds of automation in different situations are the ones most likely to succeed (the survival of the fittest).

The scenario specifications build on previous projects and experiences such as “GCDC” and “SARTRE” and integrates and extends on-going work on standards developed for example within the CAR 2 CAR Communication Consortium.

These scenarios are motivated as follows;

- They focus on realistic traffic situations that regularly occur in everyday traffic
- They contain basic manoeuvres (opening a gap, merging, lane changing, prioritising) that can be regarded as “building blocks” for a large set of possible traffic scenarios
- They are challenging for the teams on the one hand, but also realistic goals on the other hand

The scenarios have been selected as a result of an on-line survey published by Viktoria Swedish ICT. All teams that, at the time of the application, had signed a letter of intent to participate in i-GAME have been invited to propose scenarios for the competition. The response has been analysed and categorized by the project partners, all with substantial experience from evaluation, safety and performance aspects of automated vehicles.

Contents and structure of this document

This document consists of an executive summary, a background to why specific scenarios have been selected and the three scenarios in detail. Evaluation criteria are included in this document but details on the exact procedure for evaluation will be published in D7.1. Special (safety) requirements for vehicles and crews are described at an overall level in this document and will be detailed in D1.2 and D1.4.

2 Scenarios

2.1 Cooperation on highway

2.1.1 Purpose of the scenario

This scenario demonstrates advanced cooperative manoeuvers on the highway. It builds on the simpler platooning scenarios that were demonstrated in the 2011 GCDC competition. Cooperative vehicles can, better than manual and autonomous, resolve complex traffic situations in many perspectives, e.g. safety, traffic flow and energy efficiency. Participating vehicles know well beforehand that a lane up the road is blocked. By means of V2V communication they also know the intentions of vehicles close by. Hence they can take measures to effectively resolve the risk of congested traffic situations.

2.1.2 Scenario description

Two platoons are approaching a construction site on a highway. The site is out of view for all participants when the scenario starts. Left platoon (A) and right platoon (B) receive information from a roadside unit (RSU) that they are approaching a road construction site. The RSU sends a message to oncoming traffic with information about position and speed limit on the construction site. The participating vehicles must merge the two platoons into the available lane for passing the site. The merge should take place in a specified area before the Construction Site (CS). The CS starts with a (imaginary) horizontal line crossing the road at a given distance from the CS. The Competition Zone (CZ) in this scenario is divided into two parts, before construction site starts (CZ-1) and after (CZ-2). Evaluation will take place in both zones as described in 2.1.6.

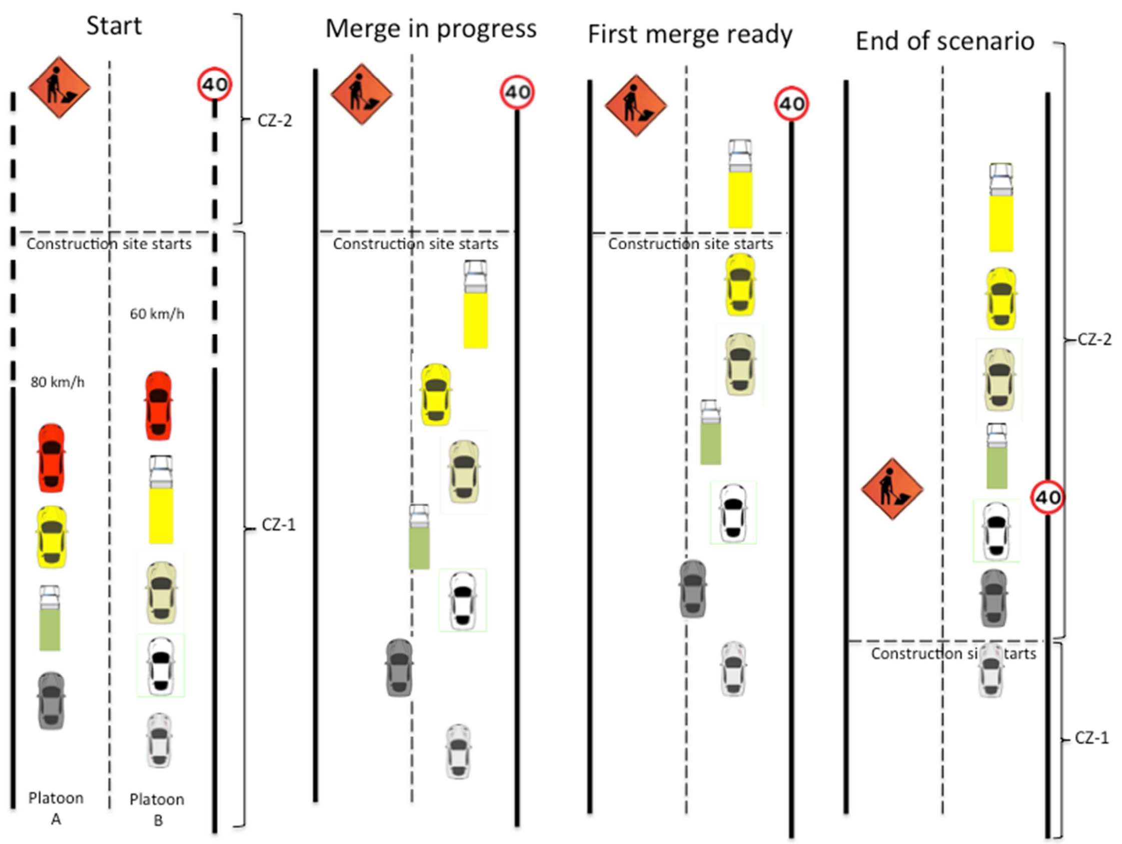

Figure 1: Scenario 1 description

2.1.3 Before scenario

The traffic on the highway should not be too dense; the time of day could be 14:00. Platoon A is driving at a speed of 80 km/h and platoon B at 60 km/h. Each platoon has an “organizer pace car” (OPC) marked red in Figure 1. The OPC in Platoon A will be the organizer reference vehicle and it will take part in the merging manoeuvre (for the purpose of creating a visibly realistic scenario for the audience).

The purpose of positioning platoons with OPCs is to support fair (group) evaluation for all teams when scenarios are repeated. When the scenario starts the OPCs will be in such positions that the merging platoon (A) will always depend on a gap being opened in platoon B. Hence the last vehicle in platoon B will always be the last vehicle in the new platoon passing into the CS. Vehicles are not required to merge in any particular order (e.g. every other vehicle) but are free to negotiate or choose any position in the new platoon, except in front of the OPC in platoon B.

2.1.4 Step-by-step

1) OPCs leads platoons to correct position for start of scenario
2) RSU communicates the position of the road work – also indicating the start-time for the competitive part of the scenario
3) Vehicles receive the message and based on position and performance they negociate a position in a planned single platoon in the correct lane.
4) Platoon B will open gaps, platoon A will adapt speed and position to the agreed gaps.
5) As soon as two vehicles from platoon A & B are ready the merging vehicle can start the manoeuver.
6) The last car in platoon B must be the last car in the single platoon formed when passing into the CS
7) The platoon enters the CS in a perfect platoon with the correct given speed.
8) The platoon continues driving and after the roadworks the first vehicle accelerates to 80 km/h, continues for some time and then decelerates to standstill.
9) The scenario ends when all participants come to a standstill.

2.1.5 Optimal scenario

The optimal performance is when the platoons merge, with a minimum jerk, in the correct lane before the start of the Construction Site.

2.1.6 Individual evaluation criteria

1) Efficiency criteria

   The goal is to increase throughput, but guarantee safety as well. Therefore, the closer a participant follows a preceding vehicle -while guaranteeing safety, the better.

   The safe distance is defined by the i-GAME organisation and will be presented in the form:

   $d_{safe} = h_{safe} * v + r_{safe}$, with *v* the host velocity.

   Let us define the error $e = d_{safe} - d_{measured}$

   The L1-norm and L2-norm of the error (*e*) will be calculated. The minimum of these will hold as performance metric:

   Efficiency_metric = $Min(||e||_1, ||e||_2)$. Hereby the L1-norm is the integral of the absolute error over the duration time in the CZ-2. The L2-norm is the integral of the squared error over time.

   This criterium will be evaluated in the CZ-2 and this will only be considered for the first vehicle following the i-GAME vehicle. If the participant prefers another spacing policy, this could be discussed with the i-GAME organisation, so the participant could be judged on following his/her proposed spacing policy.

2) Violation of the standstill part of the safety distance r_{safe} and maximum speed limit will be penalized.

2.1.7 Group evaluation criteria

1) Cooperation capability to optimize use of road space:

   The join manoeuver should be completed before the start of the CS. Penalty will be added for late merge after enetering the CS.

2) Platoon_length_metric = Average Right-lane-platoon-length over time (starting at ‘start-signal’, till last vehicle passes into the CS). The objective is to aim for a value as low as possible. Hence the team with the lowest average platoon length will get points.

2.2 Cooperative intersection

2.2.1 Purpose of the scenario

This scenario demonstrates a complicated intersection coordination activity on a country road or a street in a city. With cooperative vehicles congested traffic situations can be resolved with benefits in safety as well as environmental aspects and traffic flow. Looking further in the future it may not be necessary to have expensive traffic-controlling infrastructure such as regulation of traffic lights and sensors in the road. As vehicles are communicating and are aware of congestion they can resolve complex situations. This scenario does not require all cars to be connected; the situation will be resolved with the ones that are. The yellow cars (Figure 2) on the main road will act as pace cars, slowing down gently, to allow a safe passage for a vehicle onto a busy road or street. Algorithms and performance in this scenario could also be valid for a compound, such as construction sites and harbours.

2.2.2 Scenario description

Three competing yellow vehicles in Figure 2 (V1, PC1 and PC2) are approaching a T-intersection. There will be other vehicles on the road but they are not competing and are not communicating. All three competing vehicles pass the line of the Competition Zone (CZ) at exactly the same time (for evaluation purposes) and are not allowed to respond to communication from the other competing cars before this time. Once all the vehicles have passed into the CZ (front of vehcle) they will collaborate to allow V1 to enter the road in a safe manner. When V1 is on the main road, all vehicles accelerate to get out of the intersection as soon as possible. The scenario ends when the last of the three vehicles (front end of vehicles) has left the CZ.

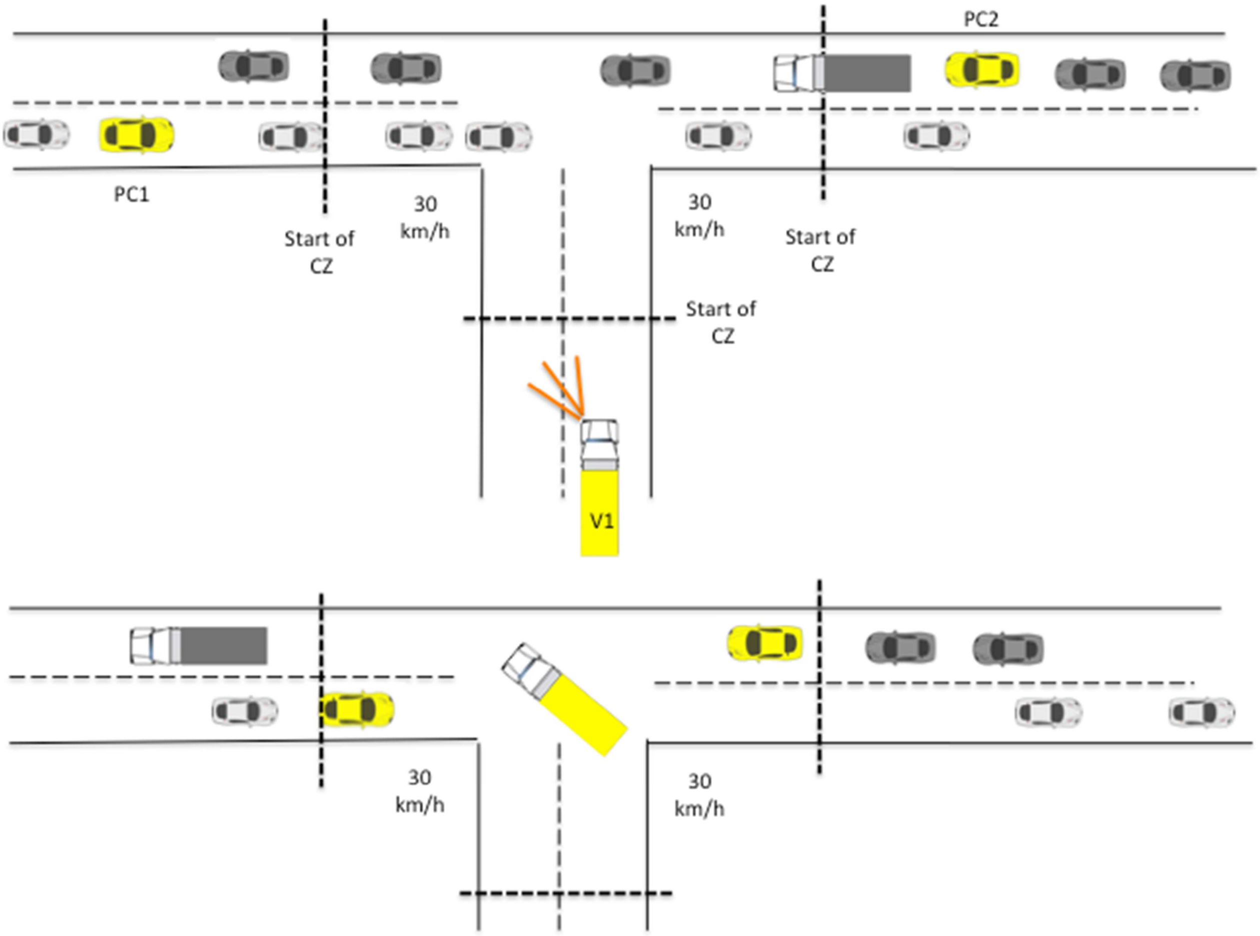

Figure 2: Scenario 2 description

2.2.3 Before scenario

The competing vehicles start at a distance from the competition zone sufficient to regulate speed so that all vehicles can enter the zone at a given time. A GPS time will be given to the teams indicating the time when the vehicles are expected to cross the line to the competition zone at a speed of 30 km/h. This means that the vehicles will collide if no negociation and actions are taken. Negociation between the vehicles cannot start until all vehicles have entered the competition zone with the front of the car. The i-GAME organisation can request a re-start in case this initial condition is not obtained.

2.2.4 Step-by-step

1. Vehicles can (for verification and safety) confirm that they have working commication from the other participants before entering the competition zone.
2. The scenario starts when the first vehicle passes into the CZ
3. Vehicles can start negociating as soon as they are inside the CZ
4. Vehicles then drive at a max speed of 30 km/h.
5. The vehicles negociate optimal speed to allow passage for V1
6. Vehicles should ideally not come to a full stop
7. Scenario ends when all vehicles have left the Competition Zone (Figure 3)

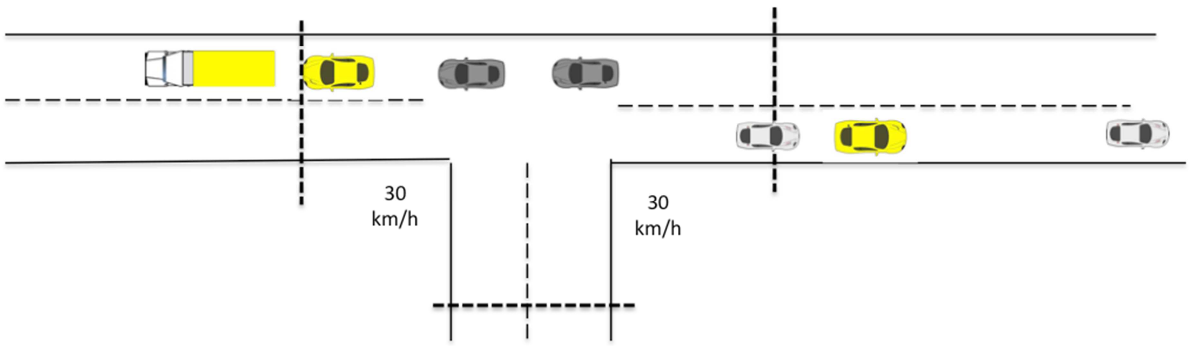

Figure 3: Scenario 2 (end of scenario)

2.2.5 Optimal scenario

All vehicles negociate a speed that is optimal allowing passage for the vehicle entering the road without stopping and/or violating safety distance / time to collision.

2.2.6 Individual evaluation criteria

1. Safety - Do not exceed the given speed limit of 30 km/h inside the competition zone
2. Safety – do not violate the safety distance of r_{safe}

2.2.7 Group evaluation criteria

1. Througput: No vehicle should come to a full stop and perform the manoeuvre.
2. Time from the first vehicle enters the CZ until the last vehicle leaves the CZ.
   Compensation for trucks regarding max speed in turn and max acceleration out of CZ will be concidered.

2.3 Emergency vehicle (demonstrator)

2.3.1 Purpose of the scenario

This scenario demonstrates how cooperative vehicles can resolve a non-anticipated traffic situation that is very common in today's traffic. When traffic is congested in a city or on a highway, drivers get confused regarding how to best act when an emergency vehicle (EV) is approaching from behind. Drivers may not hear the signal at all due to that the radio is turned on or that the driver is speaking on the phone. Also the EV approaches from behind and rear view may obscured due to a truck behind. The result is that the EV must slow down or stop to wait for vehicles to move. There is also confusion among the drivers as to which action to take to give passage to the EV, as there are no fixed rules regarding this. This creates confusion and frustration and loss of valuable time for the EV.

With cooperative vehicles this situation can be solved in an efficient and safe manner as the vehicles not only know much sooner that an EV is approaching, but they also know the intention of the EV and the drivers can get instructions on how to act, or if in fully automatic mode the car acts by itself. The vehicles can also safely continue to drive with reduced speed reducing further congestions.

2.3.2 Scenario description

This scenario is for demonstration only. It will not be evaluated as a part of the competition but the ability to participate is a requirement for the participation in GCDC.

Refer to Figure 4 for an overview. An EV is approaching a congested traffic situation and signals the intent to pass the traffic congestion in a given position (left / middle / right side). The cooperative vehicles know at which time the EV will be close and act in a cooperative manner to create room for the EV. Vehicles continue with reduced speed during the maneuver. When the EV has passed the vehicles resume position and speed.

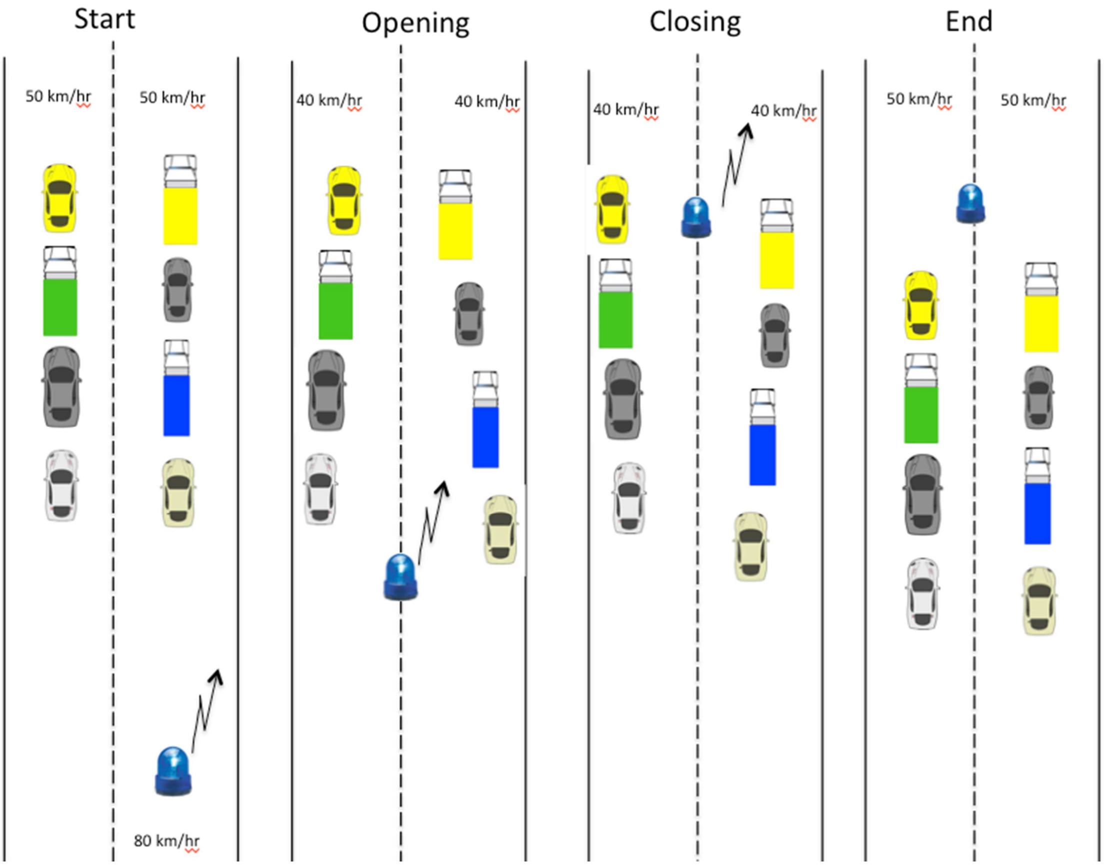

Figure 4: Scenario 3 description

2.3.3 Before scenario

Congested traffic moving at 50 km/h in both lanes. Vehicles are driving manually but with communication on. They are able to receive the signal from the EV and send the message forward to other vehicles. The EV is approaching at a speed of 80 km/hr.

The scenario starts when the rear vehicle of the congested traffic receives the signal from the EV.

2.3.4 Step-by-step

1. After receiving the EV message the vehicles act on the request of the EV.
2. The first car to receive the signal sends it on to other cars going in the same direction
3. A driver in front can only act when the signal is received in the ego vehicle
4. The cars will reduce speed to 40 km/h and allow the EV to pass at 80 km/h.

2.3.5 Optimal scenario

Participating vehicles receive the signal from the EV and transmit forward in the dense traffic, allowing the EV to pass with little or no loss of speed. Both lanes are able to continue drivning as before the signal and can move back when the EV has passed.

2.3.6 Evaluation criteria

This is not relevant as this is a demonstration only.

2.3.7 Safety requirements and abort procedures

This will be available in the document "Rules & Technology" as a result of the completed Work Package 1 on month 10.

3 Special requirements

3.1 Legal requirements

It is generally accepted that one of the main bottle necks for the deployment of automated driving in real environments comes from the legal framework. A number of studies have been and are being executed in order to further define a legal framework that balances the safe deployment of automated driving. The definition of this legal framework is out of the scope of the i-GAME project. However, the project is participating in discusion forums, such as the VRA project[1], and will contribute to the definition of updated legal requirements.

In addition to the work done for legal requirements, i-GAME is committed to implement the scenarios proposed in this deliverable according to current rules, when applicable. As discussed in the ASSESS project[2], there is no specific regulation addressing automated driving. However, some considerations derive from the 1968 Vienna Convention on Road Traffic and National Road Traffic Codes and on the other hand from product liability law (Product Liability Directive (85/374/EEC). These considerations include:

I. Overrideability of IVSS-triggered / automated interventions

From a product liability point of view, as well as with regard to the 1968 Vienna Convention on Road Traffic, automated interventions which are triggered by IVSS (Intelligent Vehicle Safety System) should be designed in a way that allows the driver to override the intervention at any time he wishes to do so.

II. Automated interventions in areas beyond human reaction capabilities

Automated interventions in areas which lie beyond human reaction capabilities represent a special case: These interventions will occur at a point in time at which the driver is unable to mitigate or avoid the accident all by himself which will comply with the will of a carefully acting driver (at least this can legally be presumed). For this reason it remains within the legal scope of interpretation to assume these automated interventions remain in line with the provisions of the Vienna Convention.

III. Information and warning strategies

Automated interventions should be preceded and accompanied by information that alerts the driver to the hazard, allowing him to take the appropriate action which at the same time puts the driver´s will forward just as far as possible: In case of the detection of an impending collision the driver's will should be called forth by corresponding warning strategies which give him the basic opportunity to initiate a braking or steering reaction by himself to mitigate or to avoid the accident – or even to override an upcoming intervention if appropriate.

From the i-GAME project scope, and considering that the objective of the project is to demonstrate automated driving in a controlled and closed environment, these considerations will be limited.

- The overrideability as a concept will be a requirement for the implementation of the scenarios. Every vehicle in the i-GAME competitions shall have a driver. This driver shall be able to abort any automated action and take control of the vehicle at all times.
- The automated / warning interventions concept will not be considered during the implementation of the scenarios, as it would be against the project scope.

[1] VRA - Support action for Vehicle and Road Automation network, GA 610737
[2] ASSESS - Assessment of Integrated Vehicle Safety Systems for improved vehicle safety, GA 233942, D2.3 – Liabilities and D2.4 Legal methodological outline

3.2 Safety requirements and abort procedures

This will be available in the document "Rules & Technology" as a result of the completed Work Package 1 on month 10.

Common requirements and guidelines used in major test tracks for vehicle testing will be taken as a reference. In this case, driving and safety regulations applicable at IDIADA's proving grounds in Santa Oliva (Spain) will be used. Requirements will include:

- Role of the GCDC controller
    - Communication with all vehicles participating in the GCDC
- Role of the GCDC safety car
- Role of the drivers in the vehicles participating in the GCDC
    - Qualifications
    - Assigned tasks within the vehicle
    - Capability of overriding vehicle actions
    - Capability of handling critical events / abort requests (training recommended)
- Requirements for the vehicles participating in the GCDC
    - Requirement of a driver in every vehicle
    - Insurance of the vehicle
    - Safety identifications (in case of specific limitations of the vehicle, such as fuel, speeds…)
    - Fitment and use of safety devices (safety vests, seatbelts, harness, suplementary restraint systems using pyrotechnic components)
    - Fixation of additional equipment into the vehicle
    - Overridability of vehicle operation

4 Conclusions

For i-GAME two competition scenarios and one demonstration scenario have been selected and elaborated. For a one-day event this is the maximum number possible taking into account that scenarios may have to be demonstrated at different physical sites (high-way and city) and the logistics connected to this.

The scenarios demonstrate the advantages of cooperative vehicles compared to autonomous or manually driven vehicles. The aim of i-GAME is to facilitate the introduction of cooperative automated vehicles in normal traffic situations. This introduction will happen over time and step by step. This is why automated vehicles will, in a foreseeable future, have to co-exist with manually driven (and autonomous) vehicles. Also, the industry will introduce different brand specific modes and degrees of automation over time. Vehicles with the best ability to adapt to this multitude of technical advancements will be the ones selected by the end user, ultimately the survival of the fittest.

V2V communication equipment and standards are already being developed and promoted as industry standard, which will facilitate the progress for higher degree of automation in traffic. In a not so distant future 4G and 5G telecommunication standards may replace the need for the (today) faster mode of V2V communication.

Scenarios 2 and 3 demonstrate situations where not all vehicles are cooperative and not necessarily automated. They can be performed today, given a certain degree of Cooperative Vehicles is deployed in traffic. These scenarios do not even require the more ad advanced V2V communication equipment but would be possible to demonstrate using the existing mobile network.

By inviting teams from as many parts of the world as possible and with a wide variety of skills, i-GAME promotes collaboration. It is not possible to win the competition by holding back on own skills. Instead it is for the benefit of all participants to share knowledge, which hopefully will accelerate the introduction of automated vehicles in real traffic.

The development of scenarios has been as open as possible to potential teams and industrial partners, using a website for the collection of ideas and opinions. After the open invitation to i-GAME at the FISITA conference in June 2014, the project has the ambition of keeping all information as transparent as possible in order to further promote collaboration between teams and industry.

5 List of abbreviations & terminology

AV

Autonomous vehicle has the capacity to drive by itself on any road and traffic situation, but not necessarily with V2V communcation. In i-GAME V2V communication (cooperative vehicles) is required and an AV with V2V communication is conciedered to be a FAV.

CZ

The **Competition Zone** indicates the area where evaluation of vehicle and group perfomace is evaluated. The zone varies depending on the scenario and is specified in each scenario description.

CV

A **Cooperative Vehicle** has the ability to communicate with other vehicles and road infrastructure such as traffic lights through vehicle-to-vehicle communication (V2V) with a given protocol.

FAV

A **Fully Automatic Vehcle** has the capacity to drive without driver intervention regarding both longitudinal and latitudinal movements (accelerate / break / steer) with the assistance of on-board systems and V2V communication.

FV

The **First Vehicle** in a platoon. We have chosen not to use the term “lead vehicle” (or similar) as the FV has no other role than being the first vehicle in the platoon. As all vehicles in i-GAME are concidered as equal, any FAV or SAV can take the role of FV.

Multi-Vendor Approach

Other previous projects have proven platooning capabilities with (potentially) higher degree of precision than possible in i-GAME, mainly for safety reasons. One important factor for automated vehicles is however cooperation between different suppliers. i-GAME acts as a facilititator to open up the potential of collaboration between different actors in the area of automated vehicles.

OPC

An **Organizer Pace Car** is an organizer vehicle developed as a reference vehicle for evaluation of performance and safety. The OPC may participate in a scenario and act as a pace car to set up teams for fair (group) evaluation.

SAV

A **Semi Automatic Vehcle** has the capacity to drive without driver intervention regarding only longitudinal movements (accelerate / break) with the assistance of on-board systems and V2V communication. Lateral movements (steering) is performed by the driver.

RSU

A **Road Side Unit** is a (mobile or fixed) communication device capable of sending and receiving signals from and to vehicles. In i-GAME this is used for transmitting signals from the organizers to the competing vehicles in some scenarios and for receiving signals from all participating vehicles for evaluation of individual and

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