### Technologies for Road Advanced Cooperative Knowledge Sharing Sensors

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Abstract:
This document describes the sensor technologies which will be investigated in TRACKSS. It provides the state-of-the-art, the identified gaps and the innovations to be performed in the frame of this project. Furthermore, specific requirements and anticipated specifications of the sensors are described.

Keywords:
TRACKSS, Cooperative, Sensors, Road, Requirements
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1. INTRODUCTION

Work package 1 ‘Requirement Assessment’ sets the basis for the TRACKSS project work. In order to achieve its objectives, i.e. to assess the requirements TRACKSS developments will have to meet, this work package has been structured into three lines of work, each one covered by a specific activity:

- Analysis and formalisation of the requirements of the new or evolved sensing technologies which will collaborate within TRACKSS operational framework (task 1.1, which results are reported in this document).
- Analysis and formalisation of the main requirements of the operational framework (task 1.2, which results are reported in Deliverable 1.2).
- Analysis of the co-operative requirements related to a whole network (task 1.3, which results are reported in Deliverable 1.3).

![Figure 1 – Requirements gathering process](image-url)
The Figure 1 shows the requirements gathering process which have consisted of a number of phases or stages and related decision points.

A preliminary study of the state of the art of Intelligent Transport Systems (ITS) involving sensor developers, transport system experts and communications experts has helped us to identify the gaps of current ITS,s and to detect potential improvements that will be tackle within this project. Certainly, pre-existing solutions have been analysed and we have tried to find out which technology resources are available. Furthermore, expert sensor developers have helped to understand the technical constraints the design will need to accommodate.

All the experts have also been involved in identifying and defining the needs or requirements to manage the accomplishment of the project goal: “Developing new systems for cooperative sensing and predicting flow infrastructure and environmental conditions surrounding traffic with a view to improve road transport operations safety and efficiency”.

Finally, it has been worthwhile to validate and refine all the requirements by some experts different from those who defined them. Thus, it has been ensured as much as possible the objectivity of the results.

In this context, this document reports on the work done within Task 1.1. The sensing technologies that will be investigated in TRACKSS have been analyzed. For each one of these technologies, the following schema has been adopted:

- First, a description of the state-of-the-art has been made.
- Then, the existing gaps have been identified.
- The next step has been the presentation of the innovations to be brought by TRACKSS for that specific technology in the framework of cooperative knowledge sharing sensors.
- As a conclusion of the above elements, the requirements, both functional and system interface, as well as the specifications associated to the sensing technology in question, have been described.

The sensing technologies described are separated into two groups: infrastructure related sensors and in-vehicle sensors.

Figure 2 - TRACKSS sensing technologies

The deliverable also describes the validation methodology applied on the requirements.
2. IDENTIFICATION OF THE REQUIREMENTS

The definition of requirements has been structured in two main sections – infrastructure and onboard sensors – in order to follow the framework proposed at the project work plan, leaving the fulfilment of the first set of requirements under the responsibility of WP3 partners – infrastructure sensors –, and the second set under the responsibility of WP4 partners – onboard sensors.

Annex I contains a summary of all these requirements, and will be the work document to be used further in the project to design the different sensors and evaluate the achievement of TRACKSS objectives.

2.1. INFRASTRUCTURE SENSORS

2.1.1. IN-ROAD INDUCTIVE LOOP SENSORS

2.1.1.1. STATE OF THE ART

Inductive Loop sensors have been used for vehicle detection since 1960. At the moment, these systems are used all around the world to determine presence, traffic flow, density and for speed measurements. In some cases, vehicle classification is possible for combining these systems. For the calculation of speed with this type of system it is necessary to use two inductive loops located to a well-known distance, known as speed trap.

An Inductive Loop is simply a coil of wire embedded in the road surface of several meters in length with several returns and isolated with cross-linked polyethylene (XLPE). The loops are installed in a variety of shapes like squares, rectangles, diamonds, circular or octagonal. Each configuration produces a different electromagnetic fields. For example, the loops in diamond form reduce the probability of detecting vehicles that circulate in adjacent lanes.

Civil works are needed to install the loop because the wire is placed in the groove and sealed with a rubbery compound like XLPE. The operation principle of the magnetic loop is based on detecting a metallic mass when it crosses over the sensorial element. When a vehicle enters or crosses the loop the body and frame provide a conductive path for the magnetic field, so it creates a resonant circuit that oscillates to a frequency between 10 and 200 KHz. As a result, the loop induction and the oscillation frequency
changes, these frequency variations produce the so called magnetic signature. This characteristic is unique from each car.

The Inductive detectors work in a sensitivity range from 20 until 1000 µH of inductance, though it is preferable that the loop and power wire work in a minimum value of 50 µH. In order to guarantee the stability, the inductance of the inductive loop should be equal or greater than the entrance inductance.

When a vehicle crosses over the inductive loop its threshold of detection changes; its inductance is reduced by the self-induction phenomenon. The inductance reduction increases the oscillation frequency. This variation in the frequency is detected by a microprocessor that determines if the signal level received must produce or not an exit signal. The systems of inductive loops that are installed nowadays work solely considering the thresholds of the signal, that is to say, they detect only the presence or the occupation time of the vehicle.

In figure 2 it is observed the variations in frequency (magnetic signature) that is generated by the crossing of vehicles over the detector. The output signal of the present inductive loops is a simple pulse or the closing of a semiconductor, meaning the presence or the absence of a vehicle.

![Figure 4 - Inductive Loop Signal](image-url)
Commercial equipments offer limited features with an appreciable range of errors in the different parameters of measurement, although these are the detectors of greater implantation in the traffic control systems. That is the main reason why they only provide a few parameters considering all the information they gather. A complete substitution of such systems by others technologies is not foreseeable in the near future. For these reasons it is considered essential to extract the maximum information that the detectors of inductive loop systems can provide. Equipping them with new algorithms of RF will allow the identification and classification of vehicles.

2.1.1.2. IDENTIFIED GAPS

As explained previously, inductive loops installed at the moment work solely considering the thresholds of the signal. Previous investigations, made by our group of investigation have demonstrated that the signals generated by these systems can provide much more information than is currently used. The signals generated by different types of vehicle have also different parameters like: statistical form, amplitude, duration, frequency spectrum, etc.

The magnetic signature of two inductive loops of different dimensions present different forms for the same type of vehicle. This means that dimensions and shapes of the inductive loops are an essential parameter, so by changing the mathematical model the correlation between the signals and the specific characteristics of the vehicle that is being detected (distribution of metallic masses, height, situation of the axes and the motor, type of motor, etc.) can be modified. At the moment, only one set of inductive loop dimensions are used. It is possible to improve the results of the actual inductive loops developing a new acquisition and signal processing system, and using the suitable algorithms.

Summarizing the main gaps in inductive loops are:

- Slow sample time (3 ms.).
- The electronics only control two inductive loops at maximum.
- Vehicles crossing between two inductive loops can not be detected correctly.
- The vehicle circulation sense can not be detected.
- The need for two inductive loops by lane for the speed calculation (speeds).
- Difficulties in vehicles detection when crossing at speed above 100 km/h.

2.1.1.3. INNOVATIONS BY TRACKSS

The signal captured by a loop varies according to the metallic structure of every vehicle. Additionally, the speed of the vehicle will deform the signal according to some standard; within this project we will study these variations in order to understand them.

The acquisition and sensor hardware would be improved mainly in the case of vehicle circulating at high speed. In this case the acquisition presents several problems due to the low amount of sampled data available.

The erroneous counting when a vehicle crosses between two inductive loops will be studied, since this error would be remarkable as sensors work only with presence/absence signals. Therefore, the complete signature of vehicle crossing the
loops would be analyzed using different techniques that allow differentiate if is one vehicle crossing over two loops or two different vehicles.
Last but not least, remark the important fact that the system will be design as a smart sensor. That means not just a common sensor with its normal capabilities but a sensor able to communicate and share information between other smart sensors.
The main goals to achieve within TRACKSS are:
- Faster sample time $\rightarrow$ 0.5 ms.
- New electronic units able to control up to 4 inductive loops.
- Study and develop new configurations to solve problems like: vehicle circulating at opposite direction, speed calculation with only one inductive loop, etc.
- Solve detection errors due to vehicles crossing between two loops.
- Vehicle detection and classification when passing at speed above 100 km/h.

2.1.1.4. REQUIREMENTS

2.1.1.4.1. Functional Requirements

The inductive loop system should be able to detect and classify vehicles in four main groups, following the standard ENV-13563. The present system is devised to work simultaneously on four inductive loops with dimensions of 2m x 2m, and minimum induction of 50 $\mu$H in each of them. The system works with a power supply of 5 VDC and current of 1 A.

The functionality of the system can be adapted to the characteristics of the equipment where it is located, independent of the traffic regulator unit used to manage it. In the case of working with conventional regulators the system would work simulating the behaviour of a single loop or a speed trap (two loops placed on the same lane at a well-known distance). In this case a signal of open/closed contact will be generated to simulate the vehicle crossing. This operation mode allows detection of vehicles crossing between two lanes eliminating the double readings, and to be able to measure speed with a single loop.

By means of signal treatment process, new parameters and data will be gathered and studied, so the precision will be increased.

2.1.1.4.2. System Interface Requirements

In order to take advantage of all the characteristics that the inductive loop system offers it must be established a high speed communications port in the regulator able to receive all data and information.

The inductive loop system should be able to communicate to the local traffic control centre using Ethernet Communication.

2.1.1.4.3. Specifications

The inductive loop system should be able to work both in conventional and with another type of geometric and electrical configuration loops.
The system is designed with loops of induction over 50 µH, in blocks of four loops that are commuted sequentially so each loop is read each 1 ms., and oscillating to a frequency next to 300 kHz.

The oscillation frequency is measured with an accuracy of 60 Hz which detects deviations about 0.02 %.

The oscillation in the loops is exponential with amplitude about 2 V.

The number of samples taken from a vehicle of 2 m. length circulating up to 120 Km/h is 120, while nowadays this number is 40.

The speed measurements will be made from the magnetic signature, since it varies for a vehicle circulating at different speeds. These measures will probably have an error about 10%.

2.1.2. Laser Scanners for infrastructure Applications

2.1.2.1. State of the Art

The current laser scanners systems use coherent light coming from an emitter laser, and reflected by the vehicle after its detection. By means of the laser technology, beams generated are parallel and coherent. At the moment the beam can measure the phase angle in the return and obtain data.

The laser sensors can use two methods for the measurements depending of the sensor type: static and dynamic. In static sensors the measurement is done by the difference of the phase angle between the light wave emitted and then received after its reflection; in dynamic sensors the usual operation consists of measuring the time of flight that represents the difference between the light emitted and received after its reflection. It calculates the time interval since the laser pulse is emitted until the signal is reflected by the object and detected back in the sensor. The measurement resolution depends on this time.

These sensors are commonly used to work in the infrared range (wavelength approximately of 0.9 µm). The beams are not used in the visible range to avoid possible distractions to the users of the road. Commonly most of these systems do a perpendicular sweeping to the road cutting cross-sectionally through the vehicles; although diagonal systems have been tried, its results were quite poor.

All the laser scanner systems use one of these two sensors. Nowadays, two different systems are mainly used to detect vehicle speed: laser scanner perpendicular to the road and laser scanner multifunction. In the first case the system is based in two perpendicular laser beams focused on the road that are interrupted successively by the crossing of vehicles. The distance between these two laser beams is known and defined by the equipment, though normalised values are about 400 mm. By means of this configuration the vehicle speed can be obtained. The most important advantage in this configuration is that the error range is determined by the thickness of each laser beam (approximately 1 mm. of diameter that represents a maximum error of measurement of 0.25%). Its main disadvantage resides in its effectiveness, since this system does not reach the 100% controlling more than two lanes with large flows of vehicles.
The second system works by making two laser scanner sweeps of the width of the road. Each sweep takes 30 measures and the sensor forms an angle between the sweeps of $10^\circ$, with the sensor scanner mounted at 7 m. of height above the road. Once the vehicle crosses the second beam, the system calculates the time difference between the first and the second cross. Once the dimensional separation between the laser beams is known, the speed of the vehicle can be calculated. This technology is being deeply developed now, but it requires a great initial investment and can be used only for one lane applications.

2.1.2.2. Identified Gaps

Nowadays, laser scanner systems present certain disadvantages. Part of their limitation is derived from the fact that they were not designed specifically for traffic control applications.

The most remarkable limitations are:

- Low rate of data acquisition, which can be a disadvantage when classifying vehicles circulating at high speed.
- The output signal is provided using non-standard communication bus.
- The laser scanner systems do not provide the acquisition and treatment software, besides they are not specialised in traffic and control applications.

The limitation of the second method is the maximum scanner time, which limits also the number of samples and, therefore, the resolution. These current laser scanner systems require mechanical parts to work that reduce its life cycle.

Summarizing the main gaps in laser scanners are:
- Impossible to measure the vehicle speeds with only one of the current systems.
- Slow scanner times (1 sample each 13ms.).
- Difficulties in vehicle detection and classification for vehicles circulating at speed above 100 km/h.
- The use of mechanical parts with rotating mirrors reduces the product life.
- Drastic changes of light on the road introduce false data.
- Laser pulses that are not received by the sensor within the time of maximum detection introduce lost reflections that produce false data.
- High costs of the commercial systems.

2.1.2.3. Innovations by TRACKSS

The first improvement relates to the acquisition system. Current laser systems use high-speed non-standard serial communication bus that forces the use of expensive non-standard serial cards. Better solutions can be proposed as translation from non-standard to other generic standard protocols such USB, parallel...

In critical cases, the acquired signal can be disturb by several noises. Thus, we propose a deep study of current extraction contour techniques in order to determine correctly the class and speed of the vehicle. Usually, once got the parameters from the system, the errors in the silhouette extraction can produce inaccuracies when determining the length and speed of the vehicles. This step should be optimised in the new system with the development of new treatment signal algorithms designed specifically for traffic applications.

The objects recognition in natural environments is a very difficult task, mainly because of the wide variety of possible objects and the impossibility to control external conditions. The number of variables that influence on vehicles characterization represents a huge amount of data to be considered in classification decisions. In this case, the problem lies in the selection of the correct variable for the classification of a specific vehicle. This is why we propose a mixed technique using wavelets and neuronal networks. After finding the important parameters using the wavelets technique, they will be classified using neuronal networks. Taking advantage of the commercial laser sensors, our system will include an effective data acquisition and treatment software.

With this system it will be created a data base from data gathered. The stored information in this database will be processed by means of the software developed. The stored information in this data base will be processed basing on a list of rules or important parameters to improve the vehicle detection and classification for further usage by other systems.

In this task the sensor will not be developed yet, so a commercial laser sensor will be used. Just the acquisition and treatment software will be developed, and a database created.

In a second step, a laser sensor would be designed to replace the commercial one used previously. In this system, mechanical parts would be replaced by new optic...
configurations without moving parts whereupon the product life would increase. Moreover, the scanner timewill be increased as well.

Last but not least, remark the important fact that the system will be designed as a smart sensor. That means not just a common sensor with its normal capabilities but a sensor able to communicate and share information between others smart sensors.

The main goals to achieve within TRACKSS are:

- Taking advantage of the commercial devices, develop a new acquisition and treatment software.
- Develop laser scanners system able to detect vehicles using only one system.
- Achieve faster scanner times.
- Optimisation of software for vehicles circulating at speed above 100 km/h.
- Study and design of new optic configurations without moving parts.
- Development of signal analysis and processing systems to avoid errors like overlap, false data, lost reflection…
- Reduce the cost of the system.

2.1.2.4. Requirements

2.1.2.4.1. Functional Requirements

The lasers scanner system in design should be located in the vertical over the road to a minimum altitude of 5 meters. After tests and validations carried out in our research group we can state that vehicle maximum height must be defined in 4 m. whereas minimum altitude does not affect to the system. This altitude can be increased as long as direct vision to the lanes is guarantee, basic premise of system successes due to the intrinsic operation of the laser.

The studies carried out by our research group provide verification that the minimum number of samples needed to be able to identify a vehicle is 20.

A sweeping speed of 1 cycle/3 ms must be achieved in order to be able to detect a vehicle of 2 m. long which circulates at 120 Km/h and guarantee a minimum of 20 readings. The ideal would be reaching a sweeping speed of 1 cycle/ms.

Climatologic inclemency (clouds, rain, changes in sunlight…) can modify the results introducing false data. In most cases these values can be detected and eliminated with the simple use of a filter. In some cases, mainly because of high humidity and the creation of temporal clouds these false data cannot be detected correctly. Therefore, data should be treated in a way to minimize the harmful effect of climatologic phenomena.

By means of the accomplishment of these requirements the laser scanner system should be able to detect and classify vehicles as well as acquire and store the silhouette of them.
2.1.2.4.2. **System Interface Requirements**

Communications between our sensor and the control unit included in the laser scanner system should be done via RS232 using an owned protocol.

In order to achieve all the characteristics that the system offers, a high speed communications port in the regulator to receive all complete information must be achieved. In this case, it could be obtained from both the information already treated by the detector system and the complete registry in real time of the measurements done by the laser scanner system. This communication would be implemented using the Ethernet protocol.

2.1.2.4.3. **Specifications**

Specification of the laser scanner positioning

<table>
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<td>Maximum measurable height (m)</td>
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<tr>
<td>Distance between both sweepings of the laser scanner (m)</td>
<td>4</td>
</tr>
<tr>
<td>Angle between two laser lines (º)</td>
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Table 1: Specification of the laser scanner positioning.

Specifications of the laser scanner

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<th>Sweeping time (cycle/ms)</th>
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<td>Angular step (º)</td>
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<td>Error in the speed measurement</td>
<td>&lt; 2.5 %</td>
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Table 2: Specifications of the laser scanner.

2.1.3. **VIDEO DETECTION SYSTEM FOR TRAFFIC CONTROL APPLICATIONS**

2.1.3.1. **STATE OF THE ART**

Detecting real-time traffic conditions is a key element to advanced traffic management and traveller information systems. Until the last decade, inductive loop detectors were the conventional method for collecting permanent on-sites traffic data.

However, following the traffic density rapid increase, the implementation of real-time traffic monitoring and control has become crucial. Immediate consequences were the need for additional and more accurate traffic data from various road actors such as vehicles, bus, pedestrians and bicycles.

In recent years, technological innovations have given rise to many new and different types of advanced traffic detectors using magnetic, ultrasonic, microwave, infrared, laser and video sensors. They provide direct measurement for counting, occupancy measurement, presence detection, queue detection, speed estimation and vehicle classification.
With the constant enhancement of microprocessors, video technologies and software, all combined with the intrinsic advantage of off-road installations, the features of video detectors came through significant changes, i.e. from measurement devices to intelligent sensing systems that are now programmable and multifunctional. The output is no longer limited to the detection of traditional presence, count, occupancy, speed and headway at a particular point of measurement (typically the loop position). It can also be done all over the image providing multiple measurement points and/or spatial information about the scene, all at the same time. Some detection systems employing intelligent algorithms can now output, for instance, queue length and incident occurrence.

Image processing sensors, signal processing hardware and software are now combined to provide application-specific capabilities. This is an attractive approach towards developing new detection systems designed for traffic control applications.

Vehicles-behaviour analysis using video systems are usually based on CCTV cameras with a set-up optimised for normal traffic surveillance, and can use specific camera for specific applications. The video systems can provide intersection control or traffic monitoring by interpreting the activity in a defined part of the road scene. Vehicle edges, corners, distance and relative height are used to decipher classification, together with vehicle count, queue, speed and occupancy. Abnormal flow behaviour is recognised and provide an indication of the occurrence of an incident. Intersection control software provides accurate presence and queue detection in addition to vehicles counts. Moreover, video has now the real potential to be used in detecting pedestrians and cyclists.

2.1.3.2. IDENTIFIED GAPS

The gaps in video detection systems for traffic control applications reside either in an inefficient management of common artefacts inherent to the video technology, or in the unexplored potential of video for enhanced traffic control applications.

Common gaps inherent to video technology are link to:
- An inappropriate perspective management
- A weak management of illumination effects (shadows, headlights projections, Glares)
- Low visibility in “no-light” areas

Those issues are well-known but they are also sufficiently under control to provide appropriate answers to traffic control applications.

For enhanced traffic control applications, the video detection systems are limited by:
- The incapacity to identify specific vehicles at long range! (~ 100m)
- The difficulty to track specific vehicles in the traffic flow in general, and in urban environments in particular
- The lack of cooperation between complementary technologies

Indeed, the most common requirements in traffic control, refer to the high level of detection accuracy on specific vehicle classes (usually buses but also trams and
emergency vehicles…) that need green extensions or green waves at signalised junctions.

The basic requirement for bus priority is that the location system should provide accurate information when a bus is at a specified point where bus priority is requested. This point will normally be at a 10-to-15 seconds journey-time before the junction, unless there is an intermediate bus stop. If there is a bus stop very near the junction, the priority request point shall be immediately after that bus stop.

Selective vehicle detection at a particular point can be provided by loops, infra-red, micro-wave, transponder, etc. If the location is subject to errors, then the priority request point shall be moved sufficiently downstream away from the bus stop, to ensure that the bus will actually have left the stop when the systems says that it is at the priority request point. However, the benefits of the bus priority will be degraded if the priority request point is too close to the junction.

Bus positioning can also be done by the way of GPS systems. However, the precision is limited to a +/- 3 meters and needs to be supplemented with a reading from the odometer when reception is poor in urban environment. The stop line crossing is only approximate with such systems.

Additionally, the systems can be affected in case of abnormal traffic situations or traffic incidents between the priority request point and the junction. They do not provide information about the effective crossing of the bus with the signal line (stop line).

Traffic status and incident detection as well as vehicle identification and tracking can usually be done through video systems. But they have difficulties in supplying a reliable bus detection/identification system in mixed or dense traffic situations, and, by way of consequence, have difficulties in providing a good vehicle tracking.

2.1.3.3. **INNOVATIONS BY TRACKSS**

Within TRACKSS, we propose to explore the potential benefit of the combination between a selective vehicle detection system (ex: advanced loop system) at particular point, and a video system in order to provide traffic analysis ahead of the bus position in real time.

- **Identification of specific vehicles at far distances (~ 100m) by way of cooperation with smart loop or smart dust sensors**
  
  We propose the use of a selective vehicle detection system (smart loop from ITACA or smart dust from UNEW) that will act as a robust trigger for the video detection and tracking. This way the video system should be able to have a good initialization of its process with using an external trigger.

- **Specific vehicles tracking in urban environment**
  
  Then, the video system can provide, each second, the exact bus position and tracking as it approaches the junction. Moreover, it can integrate the management of bus stops, traffic status between the bus and the junction in mixed traffic, and incident detection, in order to provide an advanced prediction of the bus arrival at the junction. It also can confirm that the bus has effectively
crossed the signal line (stop line). The challenge for the video will then be in the robust following of the bus itself.

This will result in an enhanced bus approach management (as well as priority management) from the triggered detection to the stop line, taking into account the traffic status ahead and the bus exact position.

Those new bus tracking and traffic status indicators will rely on the current Citilog solution for traffic control: MediaCity+ (vehicles presence and stop detection, traffic incident detection, queue length measurements, etc.)

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**Cooperation with complementary technology - Radar**

Within TRACKSS, we also propose to explore the potential benefit of the combination between two complementary technologies. The combination of sensed data available from the AC20 radar (from TRW) and the video sensing system is to be investigated to see whether two seemingly complimentary sensing technologies can lead to an enhanced sensing solution (smart sensor). The success of this cooperation will lay in the different sensing approach of sensors, and the complementary sensors capacity to fill the gaps of one another.

Offline applications will be developed to test the capability of the two systems and then, if feasible, online operation will be implemented for final testing and demonstration.

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### 2.1.3.4. REQUIREMENTS

#### 2.1.3.4.1. FUNCTIONAL REQUIREMENTS

The requirements for the selective vehicle technology are:

- High reliability of the public transport detection unit.
• Extremely low false detection rate.

This will be achieved by the cooperation purpose with other TRACKSS Sensors.

The requirements for the video detection system:

• Bus will be tracked from the selective vehicle detection system location to the stop line, typically between 0 m (the stop line) and 100 m (the selective vehicle system position).
• Bus position in meter will be given every second (1Hz).
• Notification of Bus being at its commercial stop (if there is one).
• Reliability indicator (ex: bus on tracking, bus lost). During the tracking phase, this indicator will tell if the bus is tracked by the system or if it has been lost before arriving at stop line.
• Notification of Bus having crossed the stop line (i.e. the front of the bus has passed the line).
• Traffic status between bus and stop line: Below capacity – Fluid – Dense – Congested.

2.1.3.4.2. SYSTEM INTERFACE REQUIREMENTS

• RS232 or Ethernet communication with selective vehicle detection system in order to trigger the video tracking.
• RS232 or Ethernet communication with a traffic regulation system (ex: traffic controller).

2.1.3.5. SPECIFICATIONS

• Standard CCTV / CCIR video camera with a processing unit
• The camera must be fixed (as opposed to a PTZ camera)
• Both the stop line and the selective detection system must be in the field of view of the camera (with a maximum of 80 meters of coverage)
• Camera point of view should minimize vehicles occlusions.
• Focal length directly depends on previous points.

2.1.4. SMART DUST SENSORS FOR INFRASTRUCTURE APPLICATIONS

2.1.4.1. STATE OF THE ART

The last 25 years has seen an incredible advance in computer related technologies. From the first personal computers in the early 80s through the ubiquitous Windows PC to the mobile phone, technology has fundamentally changed the way people live their lives. The 21st century will see the deployment of pervasive computing, which is a concept based on a vision described by Mark Weiser in 1991.

“The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it”.

D1.1 Requirements of the TRACKSS sensors
The essence of that vision was the creation of environments saturated with computing and wireless communications capability, yet gracefully integrated with human users. Individual devices will be embedded in everyday objects and connected to each other and to the Internet over wireless networks. Networks of devices will cooperate to achieve common goals while tolerating individual failures and changing patterns of ad-hoc communication. Networked applications will be developed and deployed throughout the networks, increasing their resiliency and overcoming the communication bottlenecks inherent in conventional architectures based on back-office hosted applications.

A number of existing technologies such as 3G, Digital Audio Broadcast (DAB) and Wireless Local Area Network (WLAN) will be combined with heterogeneous wireless networks to provide access to an ever-increasing range of services. These diverse technologies constitute the fourth generation network (4G), which is defined as a network that operates on Internet technology, combines it with other applications and technologies such as Wi-Fi and WiMAX, and runs at speeds ranging from 100 Mbps (in cell-phone networks) to 1 Gbits (in local Wi-Fi networks).

One type of the wireless networks that has emerged recently and gained more importance is the Mobile Ad-hoc NETwork (MANET). MANET is a collection of mobile computing devices which cooperate to form a dynamic network without using fixed infrastructure. In 4G networks, WLANs are used to provide a single hop access to the Internet when a mobile device is within range of an Access Point (AP). In MANETs, the devices themselves provide routing services so that a device can access the Internet even where no direct wireless connection exists between the device and an AP.

At the edge of the integrated communications infrastructure promised by 4G – and augmented by MANETs – will be wireless sensor networks. Large pervasive networks of simple devices will be deployed to gather information about the environment. These devices – called Smart Dust or motes – will autonomously form networks, forward each other’s information and act as a bridge to the roadside wired or wireless infrastructure. We will be using Smart Dust devices manufactured by Crossbow Technologies (http://www.xbow.com) called MICAz. These MICAz motes are equipped with Zigbee radio to allow them to communicate with each other, as well as with other Zigbee-ready devices. Zigbee is the name of a specification for a suite of high level communication protocols using small, low-power digital radios based on the IEEE 802.15.4 standard for Wireless Personal Area Networks (WPANs). Zigbee is intended to be used in embedded applications requiring low data rates and low power consumption, and it typically operates on the 2.4 GHz radio band.

Communication with other (non-Zigbee) devices can be achieved by connecting a MICAz mote to a programming board – which has a serial (RS-232), USB or Ethernet interface – connected to a computer that acts as a gateway to the whole Internet. The MICAz motes can also accommodate compatible sensors, allowing various measurements such as light and temperature readings, speed, and magnetic field to be taken. Figure 7 shows a MICAz mote and a sensor board that can be attached to it.
2.1.4.2. IDENTIFIED GAPS

There are a number of technological gaps which must be filled through directed research programmes. Much research is still required into the protocols used for transmission through MANETs where energy is at a premium and efficiency is paramount. More work also needs to be done to provide a bridge between the deployed MANETs and the 4G infrastructure. On top of these, there are several applications and functions in the transport domain that can be provided by using Smart Dust:

- Vehicle detection
- Vehicle counting
- Vehicle speed measurement
- Traffic density/flow measurement
- Vehicle identification
- Vehicle localisation
- Vehicle classification
- Temperature reading
- Pedestrian detection
2.1.4.3. **INNOVATIONS BY TRACKSS**

The Smart Dust is rather unique in a sense that it can be used for both the infrastructure and the on-vehicle applications.

From the Smart Dust’s perspective, TRACKSS’s main interest is on how to create Zigbee MANETs using Smart Dust devices. These ad hoc networks can be combined with other standards (such as Wi-Fi and RS-232) in order to create a bridge to the internet, providing a two-way communication means between Smart Dust devices and other sensors used in TRACKSS.

The possibility of attaching sensors to these Smart Dust devices allows various measurements to be conducted on vehicles and their surrounding environment. The quality and quantity of data collected depend on the speed of the vehicle while passing the Smart Dust sensor, as well as the distance between the vehicle and the sensor. Multiple sensors can be used to obtain more accurate results, and also to enable us to calculate secondary information about the vehicles (such as their speed and size). It is also possible to use the results gathered from the Smart Dust sensors to corroborate the measures obtained from other TRACKSS sensors.

2.1.4.4. **REQUIREMENTS**

2.1.4.4.1. **FUNCTIONAL REQUIREMENTS**

- The Smart Dust sensor shall be equipped with a processor, 512 kb flash memory for data logging, 2.4GHz 250 kbps IEEE 802.15.4 radio (Zigbee) for wireless communication, and a connector to a sensor and/or programming board.
- The range of the Smart Dust radio shall be 70m (less if there are obstacles in between).
- Information that the Smart Dust sensor can provide include temperature, light level, acceleration, sound, magnetic field, humidity and barometric pressure.
- The Smart Dust sensor shall be able to demonstrate the concept of vehicle monitoring and data collection/processing in a real-world environment using ad-hoc networks.
- For vehicle monitoring, the Smart Dust sensor shall be placed on the side of the road within 4.5m of the vehicles to be measured.
- The Smart Dust sensor shall enable the use of ad-hoc networks to support potential applications in the transport domain.

2.1.4.4.2. **SYSTEM INTERFACE REQUIREMENTS**

- Communication among Smart Dust sensors shall be using Zigbee physical and medium access (MAC) layer protocols.
- The Smart Dust sensor shall support external interface via RS-232, USB, Ethernet or Zigbee. These may also be used for communication with other sensors.
2.1.4.4.3. **SPECIFICATIONS**

**MPR2400 MICAz Mote**
- Micro processor: Atmel ATmega 128L 7.3827 MHz (8 MIPS)
- Data logging memory: 512Kb
- Communication: Zigbee (IEEE 802.15.4) - radio frequency of 2.4GHz, 250 kbps bandwidth, up to 70m range
- Power: 3V (2x AA batteries)
- 51 pin connector

**MTS310 Sensorboard**
- Light sensor (CdSe photocell), max sensitivity: light wavelength of 690 nm
- Temperature sensor, range around -40 to 70 Celcius
- Tone detector and microphone
- 4.6 KHz speaker
- 2 Axis accelerometer (+/- 2g range)
- Magnetometer (Honeywell HMC 1002 sensor), range of around 15 feet (4.5m)

**MIB510 Serial Interface Board**
- On board in-system-processor (ISP) ATmega16L with 115.2 kbaud rate
- 51 pin connector to accommodate MICAx-series motes
- RS-232 Serial Port (female)
- AC wall-power connector

2.1.5. **AIRBORNE SENSOR**

2.1.5.1. **STATE OF THE ART**

Using remote sensing methods for real time traffic measurements is an absolutely new and novel technology. The DLR has developed a prototype of a remote sensing system for airborne, online and real time traffic flow measurement. It is based on a combination of two types of optical sensors placed on an airborne platform like a helicopter, a Zeppelin or aircraft, which flies special routes following the roads or observes “hot” areas like intersections. The optical traffic flow images obtained by the sensors are processed automatically and in real time to the traffic flow parameters up to the position and velocity of single cars. The traffic parameters and the images from the observed area are downloaded to the ground traffic management centre for visualization and data fusion with other traffic sensors.

The schematic overview of prototype realization of an airborne traffic monitoring system by DLR is shown in the next two pictures. In this case remote sensors are optical sensors, like frame sensors, working in the visible and in the thermal infrared range (of the light). Figure 1 shows the onboard system of the remote sensing approach for air borne traffic data collection.
2.1.5.2. IDENTIFIED GAPS

Many specific problems have to be resolved to make the airborne traffic measurement system operational for effective use for different application scenarios like “hotspot” or wide area road network monitoring, systematic data collection for validation of other types of traffic sensors fixed on the ground, monitoring of big events or emergency situations.

The choice of an appropriate airborne platform is specific for each application scenario. Different airborne platforms can be used to carry on the airborne traffic measurement system. They have advantages and disadvantages depending on the application scenarios. Airplanes are available almost everywhere and allow quick
access in order to perform test campaigns. For scanning tasks airplanes are well suited, but they cannot observe a point over a longer period. Helicopters are highly manoeuvrable and can hover above fixed points, but their operating time is relatively limited and they produce much noise. The main advantages of an airship are: highly manoeuvrable, long endurance flight, low flying platform, low vibrations and noise.

Airborne imagery requires a high radiometric dynamic of used visible cameras. Especially in urban areas, very bright and very dark regions occur within one image due to different reflection properties of the surface. Visible CCD cameras can not always comply with those requirements. Therefore a new CMOS camera type with similar geometrical resolution, but with advanced radiometric range has to be tested and implemented within the air borne system.

The Airborne sensor system consists of two parts: one airborne part on board of an airborne platform and the second part based on the ground. Communication between two parts of the system using radio downlink was established only in one direction - from the airborne part to the ground part. Missing an up link commanding channel from ground part to the airborne platform reduces the efficiency of application of the system.

2.1.5.3. **INNOVATIONS BY TRACKSS**

The prototype of the airborne sensor system was not designed for direct cooperation with other types of traffic sensors. DLR will investigate goals to modify the AS sensor to become a “smart sensor” being able for cooperation with other smart sensors within the project concept and to fill in some of technology gaps identified above.

- Optimization of application scenarios of air-borne optical sensor system for TRACKSS scenarios. This includes analysis and choice of an appropriate airborne platform, definition of flight parameters and airborne sensor configuration for application scenario planned within the project.
- To provide new properties of airborne sensors as a cooperative smart sensor a modification of interface of AS sensor is necessary. Therefore the output traffic parameters measured and provided by an airborne system will be analysed and modified regarding to the specification of the Knowledge Sharing Model (KSM) developed in the project, which will be the entity providing sharing capabilities to the sensor.
- Investigation of a concept for interface definition to up link channel from the ground part to the airborne part of AS sensor system within the TRACKSS cooperative sensors concept.
- Implementation of monochrome CMOS camera within the airborne system to improve the availability of AS because of advanced radiometric range of CMOS camera.

2.1.5.4. **REQUIREMENTS**

2.1.5.4.1. **FUNCTIONAL REQUIREMENTS**

The functional requirements to the airborne sensor system are the following
• the Airborne sensor should provide single vehicle detection with respect to the German Standard TLS vehicle classification group 2+1 categories (passenger-car-like, truck-like, other). A short extract form TLS is shown in Annex C
• vehicle classification and vehicle speed measurements should be established lane-based and in each direction,
• shall provide single vehicle traffic parameters: position and velocity of each detected car within the field of view of visual or IR cameras in real time,
• shall provide aggregated traffic flow parameters: like averaged densities and velocities per street segments,
• shall provide online geo-referenced images and image mosaic in projection into the digital road map during the flight time.

2.1.5.4.2. **SYSTEM INTERFACE REQUIREMENTS**

• the receiver Antenna of the ground part of AS Sensor has to be placed on the appropriate place (roof of the building, tower) to provide direct view to the airborne platform during the airborne traffic monitoring,
• the system interface to the airborne sensor is defined as interface to the ground part of the AS sensor which is a personal computer with standard Ethernet connection using TCP/IP protocol (wireless or cable),
• traffic data from the airborne sensor are available during the flight campaign, but only when the airborne sensor is flying above a street and “scanning” the street segments with cameras, but not during the turn or other flight manoeuvres of the aircraft.

2.1.5.4.3. **SPECIFICATIONS**

Parameters of the airborne cameras depend on the application scenario, e.g. on expected movement and altitude of the airborne platform, on the available data transfer rate to the ground.

Traffic monitoring requires high quality images. Therefore, a set of camera parameters has to be defined in order to fulfil these requirements. A combination of different optical sensors is necessary to increase the availability of AS.

One of the most important features is the radiometric dynamics describing the number of bits per pixel per channel. As an example, an 8 bit camera is able to distinguish between 256 grey values, while a 12 bit sensor can create 4096 different grey values. The importance of these parameters becomes clear from looking at aerial photos. Especially in urban areas, very bright and very dark regions occur within one image due to totally different reflection properties of the surface (e.g. reflection from windows, drop shadows). An additional automatic exposure time control is necessary. Table 7 shows the parameters of the typical visible CCD camera.
### Table 3. Parameters of a typical visible camera configuration

Cameras working in the infrared range of the electromagnetic spectrum have the advantage to be applicable even in the night. In most cases the spectral texture in the infrared allows an easier image data interpretation than visible cameras. The main disadvantages of infrared cameras are the small number of pixels (so the swath or the ground resolution has to be reduced) and the high costs. Table 8 shows the parameters of the typical bolometer thermal IR camera.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector Type</td>
<td>VarioCAM head, JenOptik</td>
</tr>
<tr>
<td>Number of pixels</td>
<td>320 x 240</td>
</tr>
<tr>
<td>Focal distance</td>
<td>114 mm or 50 mm</td>
</tr>
<tr>
<td>Pixel size</td>
<td>45 µm</td>
</tr>
<tr>
<td>Radiometric dynamics Spectrum</td>
<td>16 Bit</td>
</tr>
<tr>
<td>Frame rate</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Ground sampling distance, flight height 1000 m</td>
<td>0.4 m</td>
</tr>
<tr>
<td>Swath width</td>
<td>128 m</td>
</tr>
</tbody>
</table>

### Table 4. Parameters of the IR camera configuration

The frame rate has to be determined according to the application. For traffic density, a low frame rate (about 0.2 Hz) could be sufficient, but for car velocity measurement, frame rates in the order of 5 Hz have to be realized (effectual by common car velocities in cities).

#### 2.1.6. ADVANCED ACC RADAR SENSOR FOR TRAFFIC MONITORING

#### 2.1.6.1. STATE OF THE ART

Radar, video and laser sensing technologies are all employed in ‘above surface’ traffic monitoring. Of these methods radar is one of the most widely used due to its ability to work in adverse lighting and weather conditions (including heavy fog, rain and snow) – conditions that can be major draw backs to optical based systems. The ability of radar to work in adverse lighting weather conditions has led to the widespread adoption of radar based technology for speed cameras and traffic monitoring systems. Doppler
radar technology has particularly been applied where speed measurement is the primary requirement.

Early radar systems transmitted powerful radio pulses and then received the reflected signals from radar reflecting objects including those that were stationary. The current radar systems employed for traffic monitoring use a continuous-wave radar rather than a series of pulses. Rather than just measure the reflected “echo” these systems measure the Doppler frequency shift between the transmitted and the received signals. The frequency shift is directly proportional to the relative speed of the detected targets and so speed measurements are easily made.

The early traffic monitoring systems used the “X band” for radar speed detection. High radar signal strength was used which is easily detected and so equipment to detect law enforcement radar became readily available enabling drivers to avoid being caught by police speed traps. Most of the current traffic monitoring and law enforcement systems use the 24GHz frequency, or "K band", However the 24 GHz frequency is absorbed by water vapour - for this reason the “K band” is typically used for metrological radar systems to detect precipitation. Compared to 24GHz radars, 77GHz radars (“W Band”) have the advantages that the radar signals are less susceptible to being absorbed by water vapour and do not share bandwidth with other systems such as weather monitoring devices. Advantageously 77GHz radars are able to be packaged more compactly (as they operate at a lower wavelength).

![Figure 10 - TRW AC20 radar sensor](image-url)

The TRW AC20 radar sensor operates in the 77GHz frequency which has been permanently licensed for automotive use. The AC20 is a Doppler radar using a Frequency Shift Keying (FSK) waveform to give high resolution. The high resolution allows the spurious echoes from stationary targets to be differentiated from moving vehicles and it also permits discrimination of different targets within the field of view. The sensor is a mass production item designed for use in road vehicles for Adaptive Cruise Control (ACC) applications that maintain the speed and safe headway of the vehicle with respect to the traffic ahead. As there may be other vehicle transmitters operating at the same frequency in the same vicinity, the AC20 has the capability to ‘frequency hop’ within its operating bandwidth. The high production volumes of ACC have resulted in unit costs that mean widespread use of the radar for traffic monitoring is not cost prohibitive.
2.1.6.2. IDENTIFIED GAPS

The AC20 radar is used to monitor the traffic surrounding a vehicle specifically for Adaptive Cruise Control (ACC) applications. As such the radar is vehicle mounted. The sensor could however be used for traffic monitoring if mounted in the infrastructure, for example, if mounted on a bridge or lamp post overlooking a highway. Such a traffic monitoring application could utilise the vehicle tracking capability of the radar in order to provide traffic statistics such as vehicle counts, flow rates and average speeds. Furthermore the radar is of the Doppler type and necessarily provides accurate (relative) speed measurements when used in ACC applications. This feature could be used to accurately detect vehicles infringing the speed limits.

A further identified gap is that the radar generates target vehicle data independently of other sensors and this data does not include classification data of the target vehicle (such as the size of vehicle that is being detected). The radar target vehicle detection could be enhanced through data fusion with other sensors. For example, a video traffic detector could share knowledge with the radar in order to provide enhanced traffic monitoring measures such as lane occupancy and inter-vehicle space measurements.

It should be noted that problems exist in overcoming the identified gap that the radar isn’t used for infrastructure mounted traffic monitoring. The off-the-shelf radar is optimized for ACC traffic monitoring in ‘two dimensions’ where the relative velocity, range and bearing to target vehicles that are moving in the same plane and at similar speeds to the host vehicle are derived and tracked. However in an infrastructure traffic monitoring application the radar will be stationary and mounted remotely from the plane of the road on which the vehicles to be detected are moving. These issues may limit the achievable positioning and speed measurement accuracy particularly as no target vehicle elevation measurements are available in this ‘three dimensional’ application (target vehicle elevation is not required in the two dimensional traffic monitoring application).

In summary, identified gaps in the application and function of the AC20 radar are:

- Stationary infrastructure mounting and operation
- Vehicle counting
- Vehicle flow rate measurement
- Average vehicle speed measurement
- Cooperation with other complimentary technologies
  - Lane occupancy measurement
  - Intervehicle space measurement

2.1.6.3. INNOVATIONS BY TRACKSS

Infrastructure mounting and operation.

TRW Conekt will investigate the feasibility of infrastructure mounting the AC20 radar, first on a bridge over a motorway, and if feasible this may be extended to intersection usage later in the project. Some of the innovations necessary are:
The radar will be looking down at an angle and so compensation for all targets and tracks being measured at this angle will be formulated. Furthermore an investigation into the possible false return reflections that may occur in this mode will be made.

- Analysis of the transformation from range/azimuth measurements to vehicle path in 3D space will be carried out and compensations implemented.
- The AC20 radar inputs of host vehicle speed and yaw rate will be modified to cope with the host being stationary.
- An investigation into auto calibration of the angle and height of the radar will be carried out.
- The current data logging/visualisation utility will be modified to perform an image perspective transform in order to overlay radar targets in the video stream for accurate visualisation of the recorded scenarios.

Vehicle Counting, Vehicle Flow Rate and Average Vehicle Speed

It is TRW Conekt's goal that the above applications will be developed in the TRACKSS project. The initial task is an analysis and potentially a development of the radar tracking algorithms. This may be possible using the current tracking algorithms which exist in the AC20. However the AC20 tracking algorithms are optimised for ACC applications and may not provide the required performance for the new TRACKSS applications. In the event that a new tracking algorithm is required, it is perceived that targets will be tracked using Extended Kalman Filtering on the raw radar data. The new tracking algorithms will be developed to perform "track to stop" and "stopped track retention" functions which will be required for accurate vehicle counting and vehicle flow measurements.

Cooperation with Video Traffic Sensor – Occupancy and Space

The combination of sensed data available from the AC20 radar and the video sensing system supplied by Citilog will be investigated to see if the two seemingly complimentary sensing technologies can support the ‘Lane Occupancy’ and ‘Intervehicle Space’ measurement applications. Offline applications will be developed to test the capability of the two systems and then, if feasible, online operation will be implemented for final testing and demonstration.

2.1.6.4. REQUIREMENTS

2.1.6.4.1. FUNCTIONAL REQUIREMENTS

- The radar will conform to all known automotive regulatory requirements.
- The radar shall operate in an infrastructure mode that is both stationary and at the height of a motorway bridge.
- The tracking algorithms shall be capable of tracking a moving object as it slows to being stationary (Track to Stop).
- The tracking algorithms shall be capable of maintaining the location of a stationary object that had previously been moving until it moves again (Stopped Track Retention).
• The system shall output a vehicle count measurement.
• The system shall output a vehicle flow rate.
• The system shall output average vehicle speed.
• The system shall have a field of view sufficient enough to have a detection footprint on the motorway to correctly detect vehicles in the new application areas.

2.1.6.4.2. SYSTEM INTERFACE REQUIREMENTS

The system interface shall be fully CAN (Controller Area Network) 2.0b compliant with the exact format and content of the CAN messages to be defined later after some of the investigations to determine what is data required and can be produced has been undertaken.

2.1.6.4.3. SPECIFICATIONS

• Case Operating Temperature -40 °C +105 °C
• Storage Temperature (no power) -40 °C +130 °C
• EMC Emissions CISPR25 – level 3 & 10dB below 95/54/EC
• EMC Susceptibility No failures up to 100 V/m
• Immersion Sealing IP6K9K
• Spray resistance IP6K9K
• Vibration DIN 60068-2-64 severity 1
• Min. Voltage +6.0V CAN operational
• Min. Voltage +10.8V Fully operational
• Max. Voltage +16.0V Fully operational
• Max. Communication start time 400ms CAN Communications active
• Max. Warm up time from -40°C 180s Fully operational
• A CAN 2.0b protocol capable interface shall be supported with the ability to operate at 250 kbps or 500 kbps and using 11 or 29 bit identifiers.
• The CAN protocol device shall offer “Bus-off”, “Bus-ack” and “Bus-stuck” conditions as status information to the software.
• The CAN bus shall be internally terminated with a high impedance termination (2.6KΩ).

2.2. VEHICLE ON-BOARD SENSORS

2.2.1. ROAD SURFACE SENSORS FOR IN-VEHICLE ICE DETECTION

2.2.1.1. STATE OF THE ART

Methods for road surface condition sensing can be categorized as either passive in-pavement sensors, or remote sensing techniques. Passive in-pavement sensors can measure pavement temperature, moisture, or both. Remote sensing techniques can be
further categorized as acoustical or optical, with optical sensors subdivided into spatial profile-, temperature-, and absorption/reflection-measuring types.

The chosen approach is a sensor for absorption spectra due to the uncertain information provided by all other sensors, as reported in several university web sites: research in this area was focused on characterizing the differences between ice and water infrared absorption spectra. Later, this research was extended into a proprietary application (unrelated to highway ice detection) capitalizing on the ability to discriminate between ice and water in the NIR, chiefly because of the ready availability of cheaper, uncooled sensors in this regime (e.g., InGaAs, PtSc, or if even shorter wavelengths can be found to work, Si detection substrates). Multispectral rationing algorithms using adjacent absorption and guard bands were developed and validated through reflectometry experiments to discern the presence of ice or water on aluminium surfaces.

2.2.1.2. IDENTIFIED GAPS

Presently used technology gaps of on board sensors

The presently used technology for ice detection consists of a thermometer: it is clear that the information coming from the air temperature measurement only is very partial and can be considered just as a generic warning.

This approach is rather inexpensive but the performances are also very poor.

As explained in the paragraph 2.2.1.3, the proposed approach will consist in the IR spectral analysis of the road surface.

Proposed technology present gaps

The Near Infrared Range (NIR) is close to visible wavelengths, and although low cost Si photodiodes and CCD arrays are not sensitive in this regime, relatively cheap solid state (e.g., InGaAs) detector-based NIR sensing systems are readily available. The scope is to detect ice within reasonable costs, a must for Fiat whose highest income comes from the small cars market, so conventional thinking which considers infrared detection to be expensive is circumvented by utilizing NIR effects. The NIR detectors differ greatly from mid- to long-wave thermal infrared band detectors, which are considerably more expensive, unreliable, and have shorter MTBF statistics.

2.2.1.3. INNOVATIONS BY TRACKSS

The first innovation is the introduction of a new principle to detect the road surface conditions: no more just an air temperature measurement but an analysis in the IR of the road surface.

The actual implementation of this principle needs the development of new, low cost detectors.

The TRACKSS objective will be the feasibility study of a novel sensor enabling the proposed innovative approach. MEMS technologies have been identified as best candidates for this purpose.

The NIR detectors, as previously stated, differ greatly from mid-to long-wave thermal infrared band detectors, which are considerably more expensive, and the TRACKSS
proposed approach is to use the NIR wavelengths (i.e. PbS sensors) implementing an optical system able to cover a wider wavelength than the traditional sensors on the market. The region explored is from the classical 800 to 3.5 micrometers. Moreover it is the first time that the IR spectroscopy on a relatively wide frequency range is used for this purpose.
A new MEMS device will be developed and its functionality verified by bench tests.

2.2.1.4. REQUIREMENTS

2.2.1.4.1. FUNCTIONAL REQUIREMENTS

- The ICE sensor will conform to all known automotive regulatory requirements
- The sensor will work under all weather conditions
- The sensor will work under all visibility conditions.
- The sensor must not need cooling
- The sensor will need a scanning system: an optical-mechanical system able to move the instantaneous field of view on the area of interest.
- The temperature will be measured in the place where the sensor will be mounted, presumably into the bumper, but other positions can also be considered.

2.2.1.4.2. SYSTEM INTERFACE REQUIREMENTS

No particular requirements are needed for System Interface Requirements. A two bits signal will be provided and any kind of interface will be available depending on the network requirements.
The system interface will be CAN (Controller Area Network) compatible.

2.2.1.4.3. SPECIFICATIONS

- Sensor Operating Temperature: -30 °C +85 °C
- Degraded function: the raw data are the Infral Red spectra taken by an on board IR spectrometer. The raw data will identify an n dimensional space (n is the number of channels of the spectrometer, i.e. the measured frequencies). In normal conditions four regions of this space will be identified as very high probability ice presence (more than 90%), intermediate ice presence probability (50-90%), low ice presence probability (10-50%), no ice presence (0-10%). In degraded function only two regions will be identified as low or high probability
- Hermeticity: According to IP67, IEC 529
- Humidity: According to IEC 68-2-3 Db (The unit should be designed to withstand high pressure washing).
- Spectral Wave Bands: Two wave bands: Near Infrared (NIR) (0,5 < \( \lambda \) <2,5 \( \mu \)m) and Short Wave Band (SWB) (2,5 < \( \lambda \) < 5,5 \( \mu \)m).
• External Operating Temp Range: External (ambient) operating Thermal range interval \(-20.0 \degree C < T < +20.0 \degree C\) External Temp

• Thermal resolution: Minimum resolvable temperature 0.1\degree C at 20 \degree C for a temperature of 300K and lower temperatures

• FOV (Field Of View): The FOV ideally is 45\degree lateral, vertically depending on the sensor location to be defined to reach a distance of 4 meters

• Acquisition Frequency: 10 Hz.
  
  Focus 0.3 (m): Minimum and maximum distance that enable the sensor to maintain its spatial resolution.

2.2.2. VIDEO CAMERAS FOR IN-VEHICLE APPLICATIONS

2.2.2.1. STATE OF THE ART

The basic components for video cameras are the lens system, the imager, a control unit, housing and the data interface to a processing unit or display.

Besides of the imager, the lens system is most important for the quality of the images. Depending on the target-costs more or less single lenses are used for construction. The lenses are mostly made of glass due to automotive environmental requirements. Lenses made of plastic, which are cheaper in costs compared to those made of glass, are currently used in low-cost products, but may have the potential to meet automotive specifications and required image quality in the future.

The imager is constructed out of a matrix of sensitive elements (e.g. 640 x 480 pixels) and senses the irradiation in a certain spectral range. Currently two different technologies for automotive applications are in use, “Charge Coupled Device” (CCD) imager and “Complementary Metal Oxide Semiconductor” (CMOS) imager. CCD-imagers are known since many years and are usually build into commercial video cameras. They have a very good dark sensitivity, but a poor dynamic range with a linear response. Other disadvantage of CCD-imagers is the “blooming”-effect, which appears when strong irradiation on few elements of the imager influences many neighbour elements, which results in a white “bloom” in the image. CMOS-imagers came in quantities into commercial market just in the last years and have then been discovered for automotive applications as well. They have a dark sensitivity which is not as good as CCD-imagers, but are available with high dynamic ranges and a non-linear response. Especially the non-linear high dynamic range in combination with much less disturbing effects compared to CCD-imagers made CMOS-imagers very interesting for in-vehicle driver assistance and safety functions.
Video cameras with both technologies are currently built into vehicles. CCD-Cameras are used since years for applications like rear-, front- and side-view monitoring, where the images are usually directly presented “as they are” or superimposed with some extension lines on LCDs in the dashboard of the vehicle. CMOS-Cameras are used for advanced driver assistance systems, like Night Vision Systems, Lane Departure/Keeping Systems, Road Sign Recognition Systems, etc. The reason is that these systems require a good image quality under as much environmental conditions as possible, because a reliable image processing for the specific function is essential. First systems based on CMOS-imagers came recently on the market in Japan and Europe.

Common resolutions of video cameras in vehicles are 640 x 480 pixels. Mostly monochrome cameras are integrated into vehicles, but colour cameras, at least CCD-types, are offered from suppliers as well.

The viewing angle of the lens system depends very much of the addressed application. Cameras for monitor applications are using wide-angle or fish-eye lens systems up to 160°, while cameras which are used to deliver images of the road scene ahead are using lens systems with viewing angles of approx. 20-30°.

The data interfaces are also depending on the application. Cameras which images are directly shown on a LCD are usually providing analogue RGB (NTSC or PAL) signals, while cameras which images are used by processing algorithms are providing their images in a digital raw format via an appropriate interface.
2.2.2.2. IDENTIFIED GAPS

One of the basic challenges with in-vehicle cameras concerns applications where the road scene ahead is to be monitored. Possible applications are enhanced night vision, lane recognition, road sign recognition and detecting vulnerable road users, vehicles and obstacles. As long as one camera is used only for one specific application, the camera can be designed to meet all requirements perfectly. But, if one camera has to be used for more than one application, it has to take into account the different requirements of the applications in terms of wider lateral areas or different distances to be monitored. For example, a detection algorithm for pedestrians in urban areas needs a wider view in lateral direction up to a distance of approx. 40m, but a night vision application which is used mostly on country roads needs a good resolution in far distances up to 150m. One theoretical solution for this could be a zoom lens, but it is practically not realizable in an automotive environment.

2.2.2.3. INNOVATIONS BY TRACKSS

Within TRACKS the identified gap is addressed by investigations on a “High-Dynamic High-Resolution CMOS Video Camera with sub-windowing technique (HDHR-Camera)”. The camera will be a monochrome camera consisting of a high resolution imager (≥750 x 480 pixels), an appropriate lens system and a control mechanism which allows different applications to select only those regions of the image which are relevant for its functionalities. Therefore, the camera can be used for different applications within the same system architecture and the applications itself can save processing time and can run more effective, because they have to process only a smaller portion of the image.

2.2.2.4. REQUIREMENTS

2.2.2.4.1. FUNCTIONAL REQUIREMENTS

The major functional requirements of the HDHR-camera concern the CMOS-imager incl. lens system and the mechanism how to retrieve the images out of the camera in a most efficient way.

The requirements concerning imager resolution and lens system are determined by the requirements of the different applications. Table 8 lists some relevant requirements per application. The HDHR-camera should be designed in a way that, in an ideal case, all application requirements are covered.
<table>
<thead>
<tr>
<th>Requirements of the TRACKSS sensors</th>
<th>Viewing distance range Meter</th>
<th>Angular Resolution Pixel / deg.</th>
<th>Horizontal field of view Degrees</th>
<th>Vertical field of view Degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane detection</td>
<td>5 – 70</td>
<td>≥ 25</td>
<td>≥ 26</td>
<td>≥ 20</td>
</tr>
<tr>
<td>Road sign recognition</td>
<td>5 – 60</td>
<td>≥ 25</td>
<td>≥ 24</td>
<td>≥ 10</td>
</tr>
<tr>
<td>Object detection in urban areas</td>
<td>2 – 60</td>
<td>≥ 25</td>
<td>≥ 40</td>
<td>≥ 20</td>
</tr>
<tr>
<td>Object detection in non-urban areas</td>
<td>40 - 120</td>
<td>≥ 25</td>
<td>≥ 20</td>
<td>≥ 15</td>
</tr>
<tr>
<td>Night vision</td>
<td>40 - 150</td>
<td>≥ 25</td>
<td>≥ 22</td>
<td>≥ 15</td>
</tr>
</tbody>
</table>

Table 5: Functional Requirements of Applications of the HDHR-Camera

Requirements, which are identical for every application, are:

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral range</td>
<td>500 – 900 nm</td>
</tr>
<tr>
<td>Frame rate</td>
<td>25 images/sec.</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>≥ 110 dB within the spectral range</td>
</tr>
<tr>
<td>Intensity resolution</td>
<td>12 Bit/pixel, grey scale</td>
</tr>
<tr>
<td>Brightness control</td>
<td>A brightness control to provide good contrast and brightness distribution of the images during all illumination conditions at day and night (at night with additional near infrared illumination) must be available</td>
</tr>
<tr>
<td>Synchronisation</td>
<td>A synchronisation mechanism, e.g. by time stamp, to synchronise data with other sensors must be available</td>
</tr>
<tr>
<td>Sun light</td>
<td>With permanent direct sun light (120.000 lx) the camera must not be damaged</td>
</tr>
<tr>
<td>Blooming</td>
<td>Over the complete dynamic range no blooming effects must occur. Anti-blooming corrections must not reduce the detection capabilities of monochromatic light sources (e.g. LED brake lights)</td>
</tr>
<tr>
<td>Stray light</td>
<td>Stray light inside the optical system must be minimized</td>
</tr>
<tr>
<td>Image windows</td>
<td>Three image-windows of different size and location should be dynamically selectable and individually transferable via the system interface</td>
</tr>
<tr>
<td>Environmental requirements</td>
<td>Meet all environmental specifications of automotive OEMs</td>
</tr>
</tbody>
</table>

Table 6: Common Functional Requirements of the HDHR-Camera

To support the applications in terms of the amount of image pixels to be processed, each application should be able to dynamically specify a window of the whole image, which has to be transferred via the image interface. This mechanism requires a bi-directional bus between the camera and the applications, with a low bandwidth for
commands to the camera and a high bandwidth for the raw image data from the camera. Each application should be able to specify a new window before every image transfer. The total number of windows and therefore the number of applications, which can request image data in parallel, will be limited to three.

2.2.2.4.2. **SYSTEM INTERFACE REQUIREMENTS**

The system interface of the HDHR-camera must be able to receive and send data from and to different applications. It covers two main tasks:

- Receiving data from an application which specify a window size.
- Sending images of a specified size to up to three control units which run the image processing algorithms.

The physical system bus interface must be able to address up to three applications and transport in a worst case three complete images within 40 ms of time.

2.2.2.4.3. **SPECIFICATIONS**

The ideal specifications for the CMOS-imager as well as the basic lens system parameters can be directly derived from the functional requirements listed in Table 10. The ideal specifications of the lens system seem to be realistic, but it would not be possible in the moment to find a suitable CMOS-imager with these specifications on the market. Therefore, the specifications will be adapted to meet those imagers which are currently available on the market, at least as advanced development samples. Table 7 gives an overview of the ideal and adapted specifications. The adapted specifications are further more divided into two different available pixel sizes of CMOS-imagers (7.5 and 10µm), which should give more or less the same results.

Compared to the ideal specifications, the adapted ones are of course a compromise, but they cover the requirements of most applications. Only the requirements of the object detection in urban and non-urban areas cannot be reached and will probably result in less performance of these applications.
Parameter | Currently adapted Specifications | Ideal Specifications
---|---|---
CMOS Imager | Resolution [Pixels] | ≥ 750 x 480 | 1500 x 750
| Size of pixel, square [µm] | 7,5 | 10 | 6
| Frame rate [FPS] | 25 | 25
| Dynamic range [dB] | ≥ 110 | ≥ 110
| Intensity resolution [Bit] | 12 | 12

Lens System | Focal length [mm] | 10 | 14 | 12

Resulting Parameters | Horizontal Field of view [°] | 31 | 30 | 41
| Vertical Field of view [°] | 20 | 20 | 21
| Angular resolution [Pixel/°] | 24 | 25 | 37

Table 7: Current and Ideal Specifications of the HDHR-Camera

The specifications concerning the system interface are determined by the image data transfer to the applications. In a worst case scenario three applications are requesting the whole image 25 times per second. This would mean: 3 x 25 x 750 x 480 x 12 bits = 304 MBit/sec. with an imager of a 750 x 480 pixels resolution. The specifications must be recalculated if an imager with higher resolution will be used.

| Bandwidth in | Approx. 3 Kbit/sec. |
| Bandwidth out | Approx. 304 MBit/sec. (depending on imager resolution) |

Table 8: System Interface Specifications of the HDHR-Camera

2.2.3. VEHICLE IDENTIFICATION SENSORS FOR IN-VEHICLE APPLICATIONS

2.2.3.1. STATE OF THE ART

The main objective of the Vehicle Identification Sensor is to provide an on-board optical vehicle identification system in order to be able to combine vehicle to vehicle radio communication with optical detection systems.

Cars will be equipped with telecommunication means to exchange data, such as the presence of an obstacle on the road. But cars are also more and more equipped with perception systems (cameras, laser scanners, radars) that enable them to explore their immediate environment, including other vehicles. The optical identification is there to identify which car, in the scene captured by these perception systems, is sending information via telecommunication.

Nowadays, the main identification systems developed use automatic identification plate recognition, or spatial pattern based techniques. These systems are limited by the accuracy of vision sensors (which induces a range limitation). Other systems use infrared light, but they use simple symbols to classify types of vehicles, rather than to individually identify them. More interesting technologies have been tested, that combine two IR beacons with a common signalling protocol by means of radio-
communication to identify vehicles. These systems are impeded by both the facts that they are vulnerable to partial occultation, and that they need a radiocommunication support signal to work. Therefore, a robust, vision-only, not spatial-pattern based and middle to long-range system does not, to our knowledge, exist.

2.2.3.2. **IDENTIFIED GAPS**

Identified gaps are both technological and functional.

**Technological gaps :**

- Dazzling effects and infrared light source confusion (traffic lights, vehicle lights, solar reflections). Our system will use a conventional CCD camera, IR-sensitive, with an IR band pass filter, as the receiver part of the sensor. The problem is that many sources, beside the IR emitter, emit IR light in the road scene. This leads to many false detections.

- Infrared emitters (vehicles) tracking and separation at far distances. Separation of two close vehicles in the image will be an issue.

**Functional gaps :**

- Quick (ideally instant) identification
- Robust to partial occultation of vehicles
- Middle to long range (>60m)
- Cooperation with other sensors
  - To validate our sensor and show its relevance
  - To build a very robust identification via multi-sensor knowledge sharing

2.2.3.3. **INNOVATIONS BY TRACKSS**

The sensor is an infrared emitter and receiver system, to identify vehicles in the driving lane and localize the signal in the referential of other in-vehicle perception sensors (cameras, laser scanners, radars).

On the leading vehicle side, a led-based infrared emitter will code the identification number of a vehicle, using a blinking protocol. Time-frequency signals will be more robustly and farther perceptible by a vision sensor than spatial patterns, who are vulnerable to both partial occultation and camera resolution. Using powerful, directional infrared LEDs can enable a longitudinal identification range of more than 60m.

On the following vehicle, we will use a low-resolution, high-frequency, infrared band pass digital camera, which detects and decodes the emitter, and localizes it in the referential of other on-board perception systems. To address the problem of IR light source confusion, the issue is to create a robust filtering algorithm that will be able to discard the wrong sources, based on geometrical and frequency analysis.

To summarize, the following gaps will be addressed :

- Dazzling effects and infrared light source confusion : addressed by filtering algorithm
• Tracking and separation: will be addressed by an efficient tracking algorithm, with data (bit) correction algorithms
• Quick identification: addressed by a high frequency/low resolution camera
• Robust to partial occultation of vehicles: addressed by the fact that we use a one spot emitter, and not 2 combined emitters or geometrical emitters
• Middle to long range: addressed by the fact that we don’t use geometrical pattern recognition, and thus are independent of the camera resolution. The range is only limited by the power of the emitter.
• Cooperation with other sensors
  o To validate our sensor and show its relevance: we will work with Bosch to combine our sensor and their camera, using Trackss Knowledge Sharing Model, to build an application that retrieves zoomed images of followed and identified vehicles
  o Very robust identification: we will work with the University of Newcastle to combine our sensor with their Smart Dust sensor which can also identify vehicles, but not localize them. So, sharing knowledge with Smart Dust will add confidence to the vehicle identification application

2.2.3.4. Requirements

2.2.3.4.1. Functional Requirements

There are six functional requirements:

• The sensor shall be able to code unique vehicle identification information.
• The sensor shall be able to localize identified vehicles in the same reference system as other in-vehicle vision systems.
• The sensor shall have a good spatial accuracy for the localization of sources in the same reference system as other in-vehicle vision systems. The accuracy shall allow to distinguish between two vehicles a range previously defined.
• The range (max distance a car can be identified) shall not be less than 60m and ideally 100m.
• The identification time (time necessary to decode the signal to get an ID) shall be as short as possible, not more than a second, ideally 1/3s.
• The number of possible ID shall be at least 32 for the TRACKSS prototype. This determines the number of bits used to code the ID, 6 bits for our requirement. Ideally, the number of possible IDs shall be huge.

2.2.3.4.2. System Interface Requirements

Our sensor will deliver, preferably using ethernet, localized IDs: an ID value plus a position in the image, so altogether, that is 1 integer and 3 floats. This info must be delivered to other perception systems, such as Bosch’s camera. So the minimal output frequency of our sensor should be around 25Hz, ideally 50Hz. Let us itemize these requirements:

• Amount of output data: 1 integer and 3 floats per cycles.
• Cycle frequency: $fs = 25Hz$. 
A data port on the sensor to transmit the data with the appropriate bit rate (min 32000 bps, see below): Ethernet or Can.

2.2.3.4.3. **SPECIFICATIONS**

The functional requirements determine constraints:

- Emitting power of the IR emitter: determined by the range requirement.
- Camera resolution: determined by the spatial accuracy of localization.
- Size (in bits) of the ID code: determined by the number of possible IDs. It is the number of data bits (6, see VI.F.5 in Annex A) + the number of frame header bits (3 or 4 start bits and 2 checksum bits). Total: 12 bits.
- IR emitter frequency: determined by the identification time and the size of the ID code requirements \( fe = \frac{\text{size of id code}}{\text{ID time}} \).
- Camera frequency: determined by the IR emitter frequency \( fc = \frac{\# \text{ images} \times \text{emitted bit}}{\text{fe}} \). A minimum of 2 images/ emitted bit is required to respect the Shannon constraint.
- Output bit rate of our sensor: it is the bit rate necessary to communicate with other sensors. It is determined by the system interface requirement. If we take an example of \( n \) valid sources in the image, 3 coordinates (= 3 floats = 3x4 bytes) and 1 id (= 1 integer = 1x4 bytes) per source, a sensor cycle frequency \( fs \), the output bit rate is: \( b = n \times (3\times4) + (1\times4) \times 8 \text{ bits} \times \text{fs} \). Example: \( n = 10, fs = 20 \text{ Hz} \rightarrow b = 32000 \text{ bps} \).

<table>
<thead>
<tr>
<th></th>
<th>Ideal specifications</th>
<th>Adapted specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emitting power</td>
<td>Tbd.</td>
<td>Tbd.</td>
</tr>
<tr>
<td>Camera resolution</td>
<td>Tbd.</td>
<td>VGA (640x480)</td>
</tr>
<tr>
<td>Size of the ID code</td>
<td>&gt; 32 bits</td>
<td>12 bits</td>
</tr>
<tr>
<td>IR emitter frequency</td>
<td>100 Hz</td>
<td>25 Hz</td>
</tr>
<tr>
<td>Camera image frequency</td>
<td>200 images/s</td>
<td>50 images/s</td>
</tr>
<tr>
<td>Output bit rate (system)</td>
<td>128000 bps</td>
<td>32000 bps</td>
</tr>
</tbody>
</table>

Table 9: Ideal and adapted Specifications of the Vehicle Identification Sensor

2.2.4. **SMART DUST SENSORS FOR IN-VEHICLE APPLICATIONS**

The analysis performed for the Smart Dust Sensor for infrastructure Application (section 2.1.4) applies also to the smart Dust Sensor for in-vehicle Applications.

2.2.4.1. **STATE OF THE ART**

Refer to 2.1.4.1 on page 22

2.2.4.2. **IDENTIFIED GAPS**
Refer to 2.1.4.2 on page 24.

2.2.4.3. INNOVATIONS BY TRACKSS

Refer to 2.1.4.3 on page 25.

2.2.4.4. REQUIREMENTS

2.2.4.4.1. FUNCTIONAL REQUIREMENTS

Refer to 2.1.4.4.1 on page 25.

2.2.4.4.2. SYSTEM INTERFACE REQUIREMENTS

Refer to 2.1.4.4.2 on page 25.

2.2.4.4.3. SPECIFICATIONS

Refer to 2.1.4.4.3 on page 25.

2.2.5. PASSIVE MM-WAVE SENSOR FOR PEDESTRIAN DETECTION

2.2.5.1. STATE OF THE ART

The use of mm-wave for the detection of pedestrians and other vulnerable road users is a totally innovative potential application of this technology. Consequently, no sensors currently exist which are designed for this application and it is our intention to investigate potential sources for suitable sensors, which then may be adapted and modified, in order to conduct a feasibility study on passive mm-wave for pedestrian detection.

Existing applications

Millimetre waves are already utilised in a large range of applications. In imaging, their shorter wavelength compared to microwaves offers higher resolution and greater bandwidth, as well as narrower beamwidths and physically smaller hardware. Millimetre waves are also better than terahertz, the infrared and the visible parts of the spectrum at penetrating obscurants such as dust and cloud. They also have better penetration through many materials than optical wavelengths.

Passive millimetre wave detection is currently widely applied in the following areas:

1) Astronomy

Many astronomical objects emit energy at millimetre wavelengths. Particular attention is paid to the main atmospheric transparency windows. Observations at these wavelengths can provide useful information on so-called ‘dark’ objects such as interstellar gas or dust clouds that are too cold to radiate in the visible waveband or even in infrared. Very sensitive radiometer arrays are used at observatories for these purposes.
2) Remote sensing
This includes both satellite-based and ground-based observations made on remote areas.

3) Atmospheric measurements
Millimetre wave radiometers are often used to observe the thermal emission lines of stratospheric trace gases in the millimetre wave bands, typically between 90 and 225 GHz. Gases such as ozone O₃, carbon dioxide (CO₂), chlorine monoxide (ClO), nitrous oxide (N₂O) and water vapour, can be detected. These observations can be carried out continuously for 24 hours a day, every day of the year, and yield information on the quantities and distributions of these gases in the atmosphere. This information is used in pollution studies and climate modelling.

4) Concealed threat detection
The use of millimetre wave imagers for detecting weapons concealed in clothing since mm-waves can penetrate clothing.

5) Personnel presence detection
Millimetre wave imagers are also used to detect the presence of illegally transported personnel in vehicles or fugitives hidden in buildings.

6) Medical diagnostics
Because millimetre wave radiation can penetrate the top millimetre or so of the skin, medical radiometers are useful in identifying such conditions as skin cancers.

2.2.5.2. IDENTIFIED GAPS

Application and performance
The application of mm-wave to the detection of pedestrians is a new research area as this technology has yet to be introduced into the automotive market. An investigation into the sensor availability and feasibility of mm-wave to this application is therefore a current technology gap.

As with infrared, human beings are not the only emitters or reflectors of mm-wave radiation. However, the high emissivity of human skin offers the possibility of distinguishing a human body from its environment. To investigate this, we need to source a suitable mm-wave sensor in order to examine what other sources of mm-wave radiation exist in the road environment which may produce false presence indications. The initial feasibility study will compare a number of specimen ‘false targets’ with a human, in order to determine whether a distinctive mm-wave ‘signature’ exists.

2.2.5.3. INNOVATIONS BY TRACKSS

Innovation: Pedestrian detection
The possibility of using a non-imaging mm-wave radiometer to detect the presence of a pedestrian (or other living creature) in the path of a vehicle has not yet been addressed, due partly to the current high cost and size of the necessary equipment. The investigation of this technology in TRACKSS is therefore fundamental innovative
research. We hope to obtain a suitable sensor in order to conduct feasibility tests on the concept of a mm-wave pedestrian detector, and that cost and size reductions can be achieved from the simplicity of the concept and the application of existing MEMS technology.

As no suitable mm-wave sensor currently exists for automotive applications, information regarding the sourcing of mm-wave technology for this application is important to progressing the transfer of the technology from other applications to the automotive market.

The objective of this phase of the project is to examine the possibility that the natural millimetre-wave emission from human skin may provide a distinctive signature which can be detected by comparatively simple equipment. It is intended to try to avoid the use of actual imaging and associated computer processing, which would increase equipment costs and is likely to result in significantly greater system response times. Furthermore, analysis of images produced by pedestrian protection sensors has been already investigated in other EC projects such as PROTECTOR and SAFE-U.

Initial trials will use a single radiometric detector to investigate the feasibility of using such a device:

- to detect the presence of a human being successfully
- to distinguish the human from the environment
- to assess the fundamental capability of the sensor in terms of range and beamwidth

2.2.5.4. REQUIREMENTS

2.2.5.4.1. FUNCTIONAL REQUIREMENTS

It is envisaged that the system will consist of two radiometric detectors to detect and triangulate a target (see Figure 13). The detectors should be capable of identifying a pedestrian by their millimetre wave radiation output. The diagram below illustrates the technique. The field of view is observed by a pair of detectors with specified separation and ‘beamwidth’. When a human ‘target’ appears in the field of view, the detectors indicate its presence to the processor. The processor will produce a ‘target present’ indication to the sensor fusion system.
Some local processing may be provided to give an indication of range. A prototype system would not use “steerable” detectors to give a variable range and bearing information, but will assume a fixed angle and separation between the detectors. Refinements of this type will be deferred to future developments.

The equipment should be capable of detecting the presence of a pedestrian at a range sufficient to give time to take preventive or avoiding action, either automatically or manually. The range requirement will be dependent on the speed at which the vehicle is travelling, and the relevant calculations will form part of the design of the system.

The functional requirements are summarised in Table 10, below.

<table>
<thead>
<tr>
<th>ID</th>
<th>Functional requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS_F_01</td>
<td>To detect mm-wave emissions from a possible target</td>
</tr>
<tr>
<td>PS_F_02</td>
<td>To distinguish this target from the background</td>
</tr>
<tr>
<td>PS_F_03</td>
<td>To determine the range of the target</td>
</tr>
<tr>
<td>PS_F_04</td>
<td>To determine the bearing of the target</td>
</tr>
</tbody>
</table>

Table 10: PMMW Pedestrian sensor functional requirements

Furthermore, the sensor should have the following requirements:
- The mm-wave sensor should also conform to all relevant automotive regulatory requirements
- The sensor should work under all weather conditions
- The sensor should work under all visibility conditions.
- The sensor shall be capable of being mounted onto the vehicle such that its function can be demonstrated

2.2.5.4.2. **SYSTEM INTERFACE REQUIREMENTS**

The system is intended to provide the following information:

**A) Primary information:**

1) A positive indication of the presence of a pedestrian or similar living creature (the hazard) in the path of the vehicle. This will take the form of a discrete binary signal (i.e. on / off) at suitable voltage levels, which may be chosen to interface with other equipment. The primary signal will operate at +12V - 0V. A level shifter can be incorporated to allow this signal to be modified to interface with external equipment. Typically this signal would be used as an interrupt to a central processor.

**B) Secondary information:**

Used to generate the ‘pedestrian presence’ signal, but available externally if required:

2) An indication of the range to the hazard. This will take the form of a digital code representing the range as a binary number of \( n \) bits, where \( n \) is dependent on the width of the data bus leading to the central processor, but will be at least \( n=8 \). Again the primary operating signal levels will be +12V - 0V.

3) An indication of the bearing of the hazard. Again, this will take the form of a digital code representing the bearing as a binary number of \( n \) bits, where \( n \) is dependent on the width of the data bus leading to the central processor, but will be at least \( n=8 \). As before the primary operating signal levels will be +12V - 0V.

4) An indication of the tracking (direction of motion) of the hazard. Again, this will take the form of a group of digital codes representing the tracking (changes in range and bearing) as a set of binary number of \( n \) bits, where \( n \) is dependent on the width of the data bus leading to the central processor, but will be at least \( n=8 \). As before the primary operating signal levels will be +12V - 0V.

The range, tracking, and bearing codes will be buffered to allow them to share an external bus, with level shifters to allow the bus signal levels to be modified if required to interface with external equipment.

5) The interface to the external system may require a number \( m \) of bi-directional bus control signals. Again these may need level-shifting before being passed to the interface control logic.

The scheme is outlined as a block diagram below in Figure 14.
The system interface requirements are summarised in Table 11, below.

<table>
<thead>
<tr>
<th>ID</th>
<th>System interface requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS_S_01</td>
<td>Pedestrian presence (primary)</td>
</tr>
<tr>
<td>PS_S_02</td>
<td>Pedestrian range (secondary)</td>
</tr>
<tr>
<td>PS_S_03</td>
<td>Pedestrian bearing (secondary)</td>
</tr>
<tr>
<td>PS_S_04</td>
<td>Pedestrian tracking (secondary)</td>
</tr>
<tr>
<td>PS_S_05</td>
<td>Interface control signals (secondary)</td>
</tr>
</tbody>
</table>

Table 11: PMMW Pedestrian sensor system interface requirements
2.2.5.4.3. **SPECIFICATIONS**

The system specification for the sensor system used for TRACKSS is dependent largely on whether a suitable sensor can be sourced for the project. The specification of the sensor used will be updated at such a time when a suitable sensor is available for feasibility assessment.

The specification will include such parameters as the RF frequency and bandwidth of the radiometers; the sensitivity of the radiometers, which will determine the operating range of the system; the field of view or beamwidth in angular measurement (vertically and horizontally); and the environmental requirements such as temperature, moisture and vibration. It will also include the electronic characteristics of the interface, such as voltage levels and bus timings.
3. **VALIDATION OF THE REQUIREMENTS**

3.1. **METHODOLOGY**

The main objective of the validation phase was to certify that the sensor requirements had been well defined for the project purposes.

The validation process has assessed the completeness of the requirements, and if they are consistent and conform to the existing standards. Furthermore, possible conflicts and technical errors have been detected and corrected, avoiding ambiguous requirements.

The validation panel was formed by all the partners in the consortium.

Each expert read and analysed the requirements document of at least two of the sensors being developed within the project, looking for possible problems, and proposing a list of solutions.

The validation process consisted of eight main steps:

1) Selection of the list of experts performing the validation. These experts were part of TRACKSS consortium, although not directly involved in the sensors requirements production.

2) Distribution of the requirements document final version. The requirements document the validation refers to had to be a final version. The validation report was not valid if the requirements document was still a draft.

3) Distribution of the validation form. The validation form has two clearly differentiated parts. The first one to be completed by the experts. The second one to be completed by the sensor developers responsible to address the experts’ findings.

4) Read and analyse the document. The experts tried to find problems, conflicts, omissions, inconsistencies, etc.

5) Complete the experts’ part of the validation form.

6) Send the validation form to the requirements document responsible person, who had to distribute it to the sensor developers responsible.

7) Modification of the requirements according to the validation results, completing the corresponding validation form section.

8) Send the validation form back to experts for agreement.

Steps 7 and 8 had several iterations. Once the agreement of the experts was reached, the final validated version of the requirements document was submitted.

The main issues that arise during the validation process can be classified as follows:

- Requirements clarification. The requirements was badly expressed or had accidentally omitted relevant information.
- Missing information. Some information was considered as missing from the requirements specification.
- Requirements conflict. There was a significant conflict between requirements. A negotiation had to take place to solve these conflicts.
Unrealistic requirements. Some requirements did not appear to be feasible with the technology available or given other constraints on the system. Requirements had to be revised in order to appear more realistic.

The validation form contained a detailed checklist to be completed by the validation panel. This list is detailed in the following lines (consult annex B for details):

- Understandability. Can readers of the documents understand what the requirements mean?
- Redundancy. Is the information unnecessarily repeated?
- Completeness. Is there any missing information in the requirements description?
- Ambiguity. Are the requirements clearly defined? Is it possible to make different interpretations of the requirements?
- Consistency. Does the requirements description contain contradictions? Are there contradictions between individual requirements and the overall system requirements?
- Organisation. Is the document structured in a sensible way? Are the descriptions of requirements organised so that related requirements are grouped?
- Conformance to standards. Do the requirements conform to defined standards?
- Traceability. Do requirements unambiguously identified include links to related requirements and to the reasons why these requirements have been included?

Finally, for each group of requirements the following checklist questions had to be answered:

- Is each requirements uniquely identified?
- Are specialised terms defined in the glossary
- Does a requirement stand on its own or do you have to examine other requirements to understand what it means?
- Do individual requirements show any inconsistency?
- Are there any redundancies in the requirements?
- If the requirements make reference to some other external resource, is it described elsewhere in the document?
- Are related individual requirement correctly grouped?

In order to make easier the traceability of the defined requirements a system for uniquely identify them was proposed. An id was created for each one of the sensors and each one of the different group of requirement being tackled (functional or system interface). This way, each requirement has a unique id:

- Id. for the sensing technology

<table>
<thead>
<tr>
<th>Inductive loop sensors</th>
<th>IL</th>
<th>Ice Detector</th>
<th>IC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser Scanners</td>
<td>LS</td>
<td>Video Cameras Vehicle</td>
<td>CV</td>
</tr>
<tr>
<td>Video Cameras Infrastructure</td>
<td>CI</td>
<td>Vehicle Identification</td>
<td>VI</td>
</tr>
</tbody>
</table>
### Table 12: List of sensors Ids.

<table>
<thead>
<tr>
<th>Smart Dust Infrastructure</th>
<th>SI</th>
<th>Smart Dust Vehicle</th>
<th>SV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airborne sensor</td>
<td>AS</td>
<td>MM-Wave Sensors</td>
<td>PMMW</td>
</tr>
<tr>
<td>ACC Radar</td>
<td>AR</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Id. for the type of requirement**

### Table 13: List of type of requirements Ids.

<table>
<thead>
<tr>
<th>Functional Requirement</th>
<th>F</th>
<th>System Requirement</th>
<th>S</th>
</tr>
</thead>
</table>

- **Numeric Id. (0-99)**

  Example: IL_F_0

### 3.2. RESULTS

The following table shows the different evolutions and versions of the requirement documents for each one of the sensing technologies involved in TRACKSS. Each sensor was reviewed by three experts from the panel of experts. None of the documents was approved in the first iteration, which helped to improve the quality of the requirements, not only from a formal point of view but also regarding the contents of the different requirement definitions.

The final approval of a sensor requirements document required the agreement of the three experts reviewing the document. This agreement was reached during the second and the third iteration of refinement in the validation process.
<table>
<thead>
<tr>
<th>Sensor ID / Step</th>
<th>1st iteration</th>
<th>1st iteration answered</th>
<th>Reqs after 1st iter.</th>
<th>2nd iteration</th>
<th>2nd iteration answered</th>
<th>Reqs after 2nd iter.</th>
<th>3rd iteration</th>
<th>.........</th>
</tr>
</thead>
<tbody>
<tr>
<td>IL</td>
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<tr>
<td>LS</td>
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<tr>
<td>CI</td>
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<tr>
<td>SI</td>
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<td>INRETS</td>
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</tr>
<tr>
<td>PMMW</td>
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<td></td>
</tr>
</tbody>
</table>

Table 14: Validation process

- **X** Request for revision
- **✓** Approved

D1.1 Requirements of the TRACKSS sensors
4. CONCLUSIONS

This document reports the work developed within work package 1 of the TRACKSS project. The definition of the requirements is not only the first phase in any development project, but also one of the most important steps to have a clear definition of the objectives to be met.

This first deliverable is focused on sensors, leaving for further studies (D1.2) the cooperative approach to be introduced by TRACKSS. Nevertheless, it presents some of the innovations foreseen, providing a first overview on how the cooperative approach could improve the performance of individual sensors.

It is noteworthy to mention that the list of sensing technologies under study in the project has increased. TRW decided to employ some of their resources allocated to future parallel developments in work package 4 to develop their own sensor in work package 3: the advance ACC radar for traffic monitoring.

With this new device, the list of Ids. for sensors and an updated set of names proposed by the sensor developers, the list of TRACKSS sensing technologies is completed.

The consortium, and any interested external party, can find in this document a well structured repository with the main characteristics of the sensors which will implement the knowledge sharing capabilities proposed in the project. This repository includes not only the identification of requirements, but also a study of the relevant state of the art and the identification of gaps and innovations.
5. GLOSSARY

- **ACC**: Adaptive Cruise Control.
- **AP**: Access Point.
- **AS**: Airborne sensor.
- **AVTIS**: All-weather Volcano Topography Imaging Sensor.
- **BIS-WDS**: Brijit Imaging Systems - Weapon Detection System.
- **Blooming**: Effect in imager-chips for video cameras. It means the effect when one or more light sensitive elements (pixels) of the imager-chip are receiving too much light and then influencing neighbour pixels e.g. by cross-talking. The effect can be seen in an image as bright (white) area which looks like a bloom.
- **BMVBW**: German Ministry of Transportation, Building of Housing.
- **CAN**: Controller Area Network. In-vehicle network protocol extensively used in the car industry.
- **CCD**: Charge Coupled Device.
- **CCIR**: Comité Consultatif International des Radiocommunications, which is the European standardization body that has set the standards for television in Europe. It was initially monochrome; therefore, today the term CCIR is usually used to refer to monochrome cameras that are used in PAL countries and by extension refers to both monochrome and colour cameras.
- **CCTV camera**: A unit containing an imaging device that produces a video signal in the baseband form, usually with synchronization pulses and colour information (composite video).
- **CDT**: Concealed Threat Detector.
- **CI**: Video camera for infrastructure applications.
- **CMOS**: Complementary Metal Oxide Semiconductor.
- **Control unit**: A box with one or more programmable devices (e.g. micro processor) and with one or more communication interfaces. It has one or more tasks in terms of applications, which usually are defined by software. Control Units inside of vehicles are for instance, a seat adjustment box, an engine controlling box or an instrument cluster. A Control Unit is also necessary to run the application software of the camera sensor.
- **CV**: Video camera for in-vehicle applications.
- **Dynamic range**: Parameter of imager-chips. It describes the relative range of light intensity the imager can measure, given in decibel (dB). A factor of 10 in light intensity equals 20dB.
- **DSS**: Decision Support System.
- **EHF**: Extremely High Frequencies.
- **EMC**: ElectroMagnetic Compatibility.
- **ERM**: Electromagnetic compatibility and Radio spectrum Matters.
• **Ethernet**: Network protocol. Large and diverse family of computer networking technologies.
• **ETSI**: European Telecommunications Standards Institute.
• **FCC**: Federal Communications Commission.
• **Float**: 32 bits floating point number.
• **FOV**: Field Of View.
• **GIS**: Geo Information System.
• **GPS**: Global Positioning System.
• **HAP**: High Altitude Platform.
• **IC**: Road surface sensor for in-vehicle ice detection.
• **ID**: Identification number.
• **IEEE 802.15.4 (Zigbee)**: IEEE standard.
• **IIS**: Intelligent Infrastructure System.
• **IL**: In-road inductive loop sensor.
• **Imager**: Silicon chip with sensitive elements, usually structured in one line or a rectangle matrix, to convert radiation within a certain spectral range into electrical current. Imagers are the "image generating" part of each camera.
• **Integer**: 32 bits integer number.
• **IR**: Infrared.
• **LED**: Light Emitting Diode
• **LS**: Laser scanner for infrastructure applications.
• **MAC**: Media Access Control.
• **MANET**: Mobile Ad-hoc Network.
• **MARZ**: Guideline for traffic computer control centres and control sub-centres.
• **MEMS**: Micro Electro Mechanical Systems.
• **MTBF**: Mean Time Between Failures.
• **NIR**: Near Infrared Range.
• **NTSC**: National Television System Comité.
• **OCR**: Optical Characters Recognition.
• **PAL**: Phase Alternating Line.
• **PC**: Passenger Car.
• **PMMW**: Passive mm wave sensor for in-vehicle pedestrian detection.
• **PTZ**: Pan Tilt Zoom.
• **RF**: Radio Frequency.
• **RFID**: Radio Frequency Identification.
• **RS232**: Asynchronous serial communication method. The word *serial* means, that the information is sent one bit at a time. *Asynchronous* tells us that the information
is not sent in predefined time slots. Data transfer can start at any given time and it is the task of the receiver to detect when a message starts and ends.

- **RTTT**: Road Transport and Traffic Telematics.
- **RWIS**: Roadway/Runway Weather Information Systems.
- **Selective Vehicle System**: System able to discriminate between a predefined vehicle type (ex: a bus) and others at a dedicated position on the road.
- **SHF**: Super High Frequencies.
- **SI**: Smart dust sensor for infrastructure applications.
- **Spectral range**: The range of wavelength of light measured in nanometres (nm).
- **SSI**: Surface Systems, Inc.
- **Stray Light**: Effect which happens in optical lens systems. It means the effect that incoming light is scattered at certain surfaces within the lens system and therefore produces disturbing artificial light beams or shadows.
- **SV**: Smart dust sensor for in-vehicle applications.
- **TBD**: To Be Defined.
- **TLS**: Transport Layer Security.
- **Traffic state**: Below capacity – Fluid – Dense – Congested.
- **UAV**: Unmanned Airborne Vehicle.
- **UHF**: Ultra High Frequencies.
- **USB**: Serial bus standard for connecting devices.
- **UVT**: Unknown Vehicle Type.
- **VI**: Vehicle identification sensor for in-vehicle applications.
- **WDS**: Weapon Detection System.
- **Window size**: The size of a part of an image of the camera. A window is usually defined as a rectangle.
- **XLPE**: Cross-linked polyethylene.
6. Bibliography

[8] LUMOS - Air-based Traffic Monitoring. German project funded by the Federal Ministry for Education and Research (BMBF)
[9] The PROMETHEUS project PRO-ART, which was supported from 1989 until 1993, dealt with automatic driving. The aim was to use artificial intelligence methods for describing the state of the vehicle and the environment and then compare the internal model with the real-life situation by means of sensor data.
### Annex A – LIST OF REQUIREMENTS

#### A.1 IN-ROAD INDUCTIVE LOOP SENSOR

<table>
<thead>
<tr>
<th>In-road inductive loop sensor</th>
<th><strong>Functional requirements</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>IL-F-0</td>
<td>The inductive loop system should be able to detect and classify vehicles in four main groups, following the standard ENV-13563.</td>
</tr>
<tr>
<td>IL-F-1</td>
<td>The inductive loop system should be able to provide an identification of the road maintenance condition.</td>
</tr>
<tr>
<td>IL-F-2</td>
<td>The inductive loop system should be able to detect vehicles passing through two different inductive loops, avoiding double readings of the same vehicle.</td>
</tr>
<tr>
<td>IL-F-3</td>
<td>The inductive loop system should be able to work with four different inductive loops with dimensions of 2x2m² and a minimum induction in each of 50µH.</td>
</tr>
<tr>
<td>IL-F-4</td>
<td>When working with regulators the system should be able to work simulating the behaviour of a single loop or a speed trap.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>System interface requirements</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>IL-S-0</td>
</tr>
<tr>
<td>IL-S-1</td>
</tr>
</tbody>
</table>
### A.2 LASER SCANNER FOR INFRASTRUCTURE APPLICATIONS

<table>
<thead>
<tr>
<th>Lasser scanner for infrastructure applications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Functional requirements</strong></td>
</tr>
<tr>
<td>LS-F-0 The laser scanner system should be able to allow the acquisition and storage of silhouette of vehicles.</td>
</tr>
<tr>
<td>LS-F-1 The laser scanner system should be able to detect vehicles.</td>
</tr>
<tr>
<td>LS-F-2 The laser scanner system should be able to classify vehicles.</td>
</tr>
<tr>
<td>LS-F-3 The lasers scanner system should be located in the vertical of the road to a minimum altitude of 5 meters.</td>
</tr>
<tr>
<td>LS-F-4 The lasers scanner system must have direct vision to the lanes.</td>
</tr>
<tr>
<td><strong>System interface requirements</strong></td>
</tr>
<tr>
<td>LS-S-0 The communication between the sensor and the laser scanner system should be done via RS232 using an owned protocol.</td>
</tr>
<tr>
<td>LS-S-1 The laser scanner system should be able to communicate to the local traffic control centre using Ethernet Communication.</td>
</tr>
</tbody>
</table>
## Video Detection System for infrastructure applications

### Functional requirements

| CI-F-0 | Bus will be tracked from the selective vehicle detection system location to the stop line, typically between 0 m (the stop line) and 100 m (the selective vehicle system position). |
| CI-F-1 | Bus position in meters will be given every second (1Hz). |
| CI-F-2 | Bus at its commercial stop notification (if there is one). |
| CI-F-3 | Reliability Indicator (ex: bus on tracking, bus lost). During the tracking phase this indicator will inform if the bus is tracked by the system or if it has been lost before arriving the stop line. |
| CI-F-4 | Bus passed through the stop line notification (i.e. the front of the bus has passed through the line). |
| CI-F-5 | Traffic state between bus and stop line: Below capacity – Fluid – Dense – Congested. |

### System interface requirements

| CI-S-0 | RS232 or Ethernet Communication with selective vehicle Detection system in order to trigger the video tracking. |
| CI-S-1 | RS232 or Ethernet Communication with a traffic regulation system (ex: traffic controller). |
### A.4 SMART DUST SENSOR FOR INFRASTRUCTURE APPLICATIONS

<table>
<thead>
<tr>
<th>Smart dust sensor for infrastructure applications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Functional requirements</strong></td>
</tr>
<tr>
<td>SI-F-0</td>
</tr>
<tr>
<td>SI-F-1</td>
</tr>
<tr>
<td>SI-F-2</td>
</tr>
<tr>
<td>SI-F-3</td>
</tr>
<tr>
<td>SI-F-4</td>
</tr>
<tr>
<td>SI-F-5</td>
</tr>
<tr>
<td><strong>System interface requirements</strong></td>
</tr>
<tr>
<td>SI-S-0</td>
</tr>
<tr>
<td>SI-S-1</td>
</tr>
</tbody>
</table>
## A.5 AIRBORNE SENSOR

<table>
<thead>
<tr>
<th><strong>Airborne Sensor</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Functional requirements</strong></td>
<td></td>
</tr>
<tr>
<td>AS-F-0</td>
<td>Airborne sensor should provide single vehicle detection with respect to the German Standard TLS vehicle classification group 2+1 categories (vehicle-like, truck-like, other).</td>
</tr>
<tr>
<td>AS-F-1</td>
<td>Vehicle classification and vehicle speed measurements should be established lane-based and in each direction.</td>
</tr>
<tr>
<td>AS-F-2</td>
<td>Shall provide single vehicle traffic parameters: position and velocity of each detected car within the field of view of visual or IR cameras in real time.</td>
</tr>
<tr>
<td>AS-F-3</td>
<td>Shall provide aggregated traffic flow parameters: like averaged densities and velocities per street segments.</td>
</tr>
<tr>
<td>AS-F-4</td>
<td>Shall provide online georeferenced images and image mosaic in projection into the digital road map during the flight time.</td>
</tr>
<tr>
<td><strong>System interface requirements</strong></td>
<td></td>
</tr>
<tr>
<td>AS-S-0</td>
<td>Receiver Antena of the ground station has to be placed on the appropriate place (roof of the building, tower) to provide direct line of seen to the airborne platform during the airborne traffic monitoring.</td>
</tr>
<tr>
<td>AS-S-1</td>
<td>The system Interface from ground part of AS sensor to the Trackss network shall be done using Ethernet with TCP/IP protocol (wireless or cable).</td>
</tr>
<tr>
<td>AS-S-2</td>
<td>Traffic data from airborne sensor are available during the flight campaign, means only when the airborne sensor is flying above a street and &quot;scanning&quot; the street segments with cameras, but not during the turn or other flight manoeuvres of the aircraft.</td>
</tr>
</tbody>
</table>
### Advanced AC20 radar sensor for traffic monitoring

#### Functional requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR-F-0</td>
<td>The radar will conform to all known automotive regulatory requirements.</td>
</tr>
<tr>
<td>AR-F-1</td>
<td>The radar shall operate in an infrastructure mode that is both stationary and at the height of a motorway bridge.</td>
</tr>
<tr>
<td>AR-F-2</td>
<td>The tracking algorithms shall be capable of tracking a moving object as it slows to being stationary (Track To Stop).</td>
</tr>
<tr>
<td>AR-F-3</td>
<td>The tracking algorithms shall be capable of maintaining the location of a stationary object that had previously been moving until it moves again (Stopped Track Retention).</td>
</tr>
<tr>
<td>AR-F-4</td>
<td>The system shall output a vehicle count measurement.</td>
</tr>
<tr>
<td>AR-F-5</td>
<td>The system shall output a vehicle flow rate.</td>
</tr>
<tr>
<td>AR-F-6</td>
<td>The system shall output average vehicle speed.</td>
</tr>
<tr>
<td>AR-F-7</td>
<td>The system shall have a field of view sufficient enough to have a detection footprint on the motorway to correctly detect vehicles in the new application areas.</td>
</tr>
</tbody>
</table>

#### System interface requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR-S-0</td>
<td>The system interface shall be fully CAN (Controller Area Network) 2.0b compliant with the exact format and content of the CAN messages to be defined later after some of the investigations to determine what is data required and can be produced has been undertaken.</td>
</tr>
</tbody>
</table>
## A.7 Road Surface Sensors for In-vehicle Ice Detection

### Functional requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC-F-0</td>
<td>Full function: Sensor Max operating temperature: 85 degrees Celsius.</td>
</tr>
<tr>
<td>IC-F-1</td>
<td>Full function: Sensor Min operating temperature: -30 degrees Celsius. The temperature is measured in the place where the sensor will be mounted, presumably into the bumper, but we cannot exclude other positions.</td>
</tr>
<tr>
<td>IC-F-2</td>
<td>Degraded Function: The raw data are the Infra Red spectra taken by an on board IR spectrometer. The raw data will identify an n dimensional space (n is the number of channels of the spectrometer, i.e. the measured frequencies). In normal conditions four regions of this space will be identified as very high probability ice presence (more than 90%), intermediate ice presence probability (50-90%), low ice presence probability (10-50%), no ice presence (0-10%). In degraded function only two regions will be identified as low or high probability.</td>
</tr>
<tr>
<td>IC-F-3</td>
<td>Degraded Function: The unit shall send out a fault message over the CAN (Controller Area Network) bus when full performance is not guaranteed. Comment: Above temperatures are atmospheric and does not include internal heat build-up.</td>
</tr>
<tr>
<td>IC-F-4</td>
<td>Hermeticity: According to IP67, IEC 529.</td>
</tr>
<tr>
<td>IC-F-5</td>
<td>Humidity: According to IEC 68-2-3 Db. Comment: The unit should be designed to withstand high pressure washing.</td>
</tr>
<tr>
<td>IC-F-6</td>
<td>Weather conditions: The unit should work under all weather conditions.</td>
</tr>
<tr>
<td>IC-F-7</td>
<td>Visibility: The unit should work under all visibility conditions.</td>
</tr>
<tr>
<td>IC-F-8</td>
<td>Dust: The unit should withstand road dust.</td>
</tr>
<tr>
<td>IC-F-9</td>
<td>Atmospheric radiation: The housing should be resistant to ultraviolet radiation.</td>
</tr>
<tr>
<td>IC-F-10</td>
<td>Resistance to vibration: According to IEC 68-2-6 FC.</td>
</tr>
<tr>
<td>IC-F-11</td>
<td><strong>External Operating Temp Range</strong>&lt;br&gt;External (ambient) operating Thermal range interval $-20,0 \degree C &lt; T &lt; +20,0 \degree C$ External Temp $-30 \degree C$ would be better, but it would be difficult to find on the market the IR sensors. In the requirements we could define $-30\degree$ but in the specifications will remain $-20\degree$.</td>
</tr>
<tr>
<td>IC-F-12</td>
<td><strong>Thermal resolution:</strong> Minimum resolvable temperature 0,1\degree C at 20 \degree C for a temperature of 300K and lower temperatures.</td>
</tr>
<tr>
<td>IC-F-13</td>
<td><strong>FOV (Field Of View):</strong> The FOV ideally is 45\degree lateral, vertically depending on the sensor location to be defined to reach a distance of 4 meters.</td>
</tr>
<tr>
<td>IC-F-14</td>
<td><strong>Acquisition Frequency: 10 Hz.</strong> Information that the sensor can provide in a second.</td>
</tr>
<tr>
<td>IC-F-15</td>
<td>Focus 0.3 (m): Minimum and maximum distance that enable the sensor to maintain its spatial resolution.</td>
</tr>
<tr>
<td>--------</td>
<td>--------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>IC-F-16</td>
<td>Uncooled The sensor must not need cooling</td>
</tr>
<tr>
<td>IC-F-17</td>
<td>Output No particular requirements are needed for System Interface Requirements. A two bits signal will be provided and any kind of interface will be available depending on the network requirements.</td>
</tr>
<tr>
<td>IC-F-18</td>
<td>Scanning system: The requirement is to eventually change the measuring area with an optical-mechanical system able to move the instantaneous field of view on the area of interest.</td>
</tr>
</tbody>
</table>
A.8 VIDEO CAMERA FOR IN-VEHICLE APPLICATIONS

<table>
<thead>
<tr>
<th>Functional requirements</th>
<th>Video camera for in-vehicle applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV-F-0</td>
<td>The camera must provide gray-scale images with good contrast and brightness distribution during day and night (at night with additional near infrared illumination).</td>
</tr>
<tr>
<td>CV-F-1</td>
<td>For function <em>Lane Detection</em>: Viewing distance range [Meter]: 5 – 70 Angular Resolution [Pixel / deg.]: ≥ 25 Horizontal field of view [Degrees]: ≥ 26 Vertical field of view [Degrees]: ≥ 20</td>
</tr>
<tr>
<td>CV-F-2</td>
<td>For function <em>Road sign recognition</em>: Viewing distance range [Meter]: 5 – 60 Angular Resolution [Pixel / deg.]: ≥ 25 Horizontal field of view [Degrees]: ≥ 24 Vertical field of view [Degrees]: ≥ 10</td>
</tr>
<tr>
<td>CV-F-3</td>
<td>For function <em>Object detection in urban areas</em>: Viewing distance range [Meter]: 40 – 120 Angular Resolution [Pixel / deg.]: ≥ 25 Horizontal field of view [Degrees]: ≥ 40 Vertical field of view [Degrees]: ≥ 20</td>
</tr>
<tr>
<td>CV-F-4</td>
<td>For function <em>Object detection in non-urban areas</em>: Viewing distance range [Meter]: 5 – 70 Angular Resolution [Pixel / deg.]: ≥ 35 Horizontal field of view [Degrees]: ≥ 20 Vertical field of view [Degrees]: ≥ 15</td>
</tr>
<tr>
<td>CV-F-5</td>
<td>For function <em>Night Vision</em>: Viewing distance range [Meter]: 40 – 150 Angular Resolution [Pixel / deg.]: ≥ 25 Horizontal field of view [Degrees]: ≥ 22 Vertical field of view [Degrees]: ≥ 15</td>
</tr>
<tr>
<td>CV-F-6</td>
<td>Spectral range: 500 – 900 nm.</td>
</tr>
<tr>
<td>CV-F-7</td>
<td>Frame rate: 25 images/sec.</td>
</tr>
<tr>
<td>CV-F-8</td>
<td>Dynamic range: ≥ 110 dB within the spectral range.</td>
</tr>
<tr>
<td>CV-F-9</td>
<td>Intensity resolution: 12 Bit/pixel, grey scale.</td>
</tr>
<tr>
<td>CV-F-10</td>
<td>A brightness control to provide good contrast and brightness distribution of the images during all illumination conditions at day and night (at night with additional near infrared illumination) must be available.</td>
</tr>
<tr>
<td>CV-F-11</td>
<td>A synchronisation mechanism, e.g. by time stamp, to synchronise data with other sensors must be available.</td>
</tr>
<tr>
<td>---------</td>
<td>----------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>CV-F-12</td>
<td>With permanent direct sun light (120,000 lx) the camera must not be damaged.</td>
</tr>
<tr>
<td>CV-F-13</td>
<td>Over the complete dynamic range no blooming effects must occur. Anti-blooming corrections must not reduce the detection capabilities of monochromatic light sources (e.g. LED brake lights).</td>
</tr>
<tr>
<td>CV-F-14</td>
<td>Stray light must be minimized.</td>
</tr>
<tr>
<td>CV-F-15</td>
<td>Three image-windows of different size and location should be dynamically selectable and individually transferable via the system interface.</td>
</tr>
<tr>
<td>CV-F-16</td>
<td>Meet all environmental specifications of automotive OEMs.</td>
</tr>
</tbody>
</table>

**System interface requirements**

| CV-S-0 | The system interface of the camera must be able to receive and send data from and to different control units. It covers two main tasks:  
- Receiving data from an application which specify a window size.  
- Sending images of a specified size to the application. |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CV-S-1</td>
<td>The physical system bus interface must be able to address up to three applications and transport in a worst case three complete images within 40 ms of time.</td>
</tr>
</tbody>
</table>
### A.9 VEHICLE IDENTIFICATION SENSOR FOR IN-VEHICLE APPLICATIONS

<table>
<thead>
<tr>
<th>Vehicle identification sensor for in-vehicle applications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Functional requirements</strong></td>
</tr>
<tr>
<td>VIF-0 The sensor shall be able to code unique vehicle identification information.</td>
</tr>
<tr>
<td>VIF-1 The sensor shall be able to localize identified vehicles in the same reference system as other in-vehicle vision systems.</td>
</tr>
<tr>
<td>VIF-2 The sensor shall have a good spatial accuracy for the localization of sources in the same reference system as other in-vehicle vision systems. The accuracy shall allow to distinguish between two vehicles at the range defined in VIF.3.</td>
</tr>
<tr>
<td>VIF-3 The range (max distance a car can be identified) shall not be less than 60m and ideally 100m.</td>
</tr>
<tr>
<td>VIF-4 The identification time (time necessary to decode the signal to get an ID) shall be as short as possible, not more than a second, ideally 1/3s.</td>
</tr>
<tr>
<td>VIF-5 The number of possible ID shall be at least 32 for the Trackss prototype. This determines the number of bits used to code the ID, 6 bits for our requirement. Ideally, the number of possible IDs shall be huge.</td>
</tr>
<tr>
<td><strong>System interface requirements</strong></td>
</tr>
<tr>
<td>VI-S-0 Amount of output data : 1 integer and 3 floats per cycles.</td>
</tr>
<tr>
<td>VI-S-1 Cycle frequency : fs = 25Hz.</td>
</tr>
<tr>
<td>VI-S-2 A data port on the sensor to transmit the data with the appropriate bitrate (min 32000 bps, see below) : Ethernet or CAN.</td>
</tr>
</tbody>
</table>
## A.10 Passive MM Wave Sensor for In-Vehicle Pedestrian Detection

### Passive mm wave sensor for in-vehicle pedestrian detection

<table>
<thead>
<tr>
<th>Functional requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PMMW_F_00</strong> Pedestrian presence.</td>
</tr>
<tr>
<td>A positive indication of the presence of a pedestrian or similar living creature (the target) in the path of the vehicle. The equipment is not required to distinguish between a human and another living creature such as a horse or an elk. The presence indication will take the form of a dedicated binary code of at least one n-bit binary number, where n is dependent on the width of the data bus leading to the system interface, but will be at least ( n=8 ).</td>
</tr>
<tr>
<td><strong>PMMW_F_01</strong> To detect mm-wave emissions from a possible target.</td>
</tr>
<tr>
<td>This will require a non-imaging radiometer responding to mm-wave radiation in the region 90GHz - 120GHz. Exact frequency and bandwidth to be determined.</td>
</tr>
<tr>
<td><strong>PMMW_F_02</strong> To distinguish this target from the background by measuring radiation strength above a certain threshold level (to be determined).</td>
</tr>
<tr>
<td><strong>PMMW_F_03</strong> To determine the range of the target.</td>
</tr>
<tr>
<td>The equipment should be capable of detecting the presence of a target at a range sufficient to give time to take preventive or avoiding action, either automatically or manually. The range requirement will be dependent on the speed at which the vehicle is travelling, and the relevant calculations will form part of the design of the system. The range to the target will take the form of a digital code representing the range as a binary number of ( n ) bits, where ( n ) is dependent on the width of the data bus leading to the system interface, but will be at least ( n=8 ).</td>
</tr>
<tr>
<td><strong>PMMW_F_04</strong> To determine the bearing of the target.</td>
</tr>
<tr>
<td>The equipment should be capable of determining the bearing of the target, that is, the position of the target relative to the centre line of the vehicle. The relevant calculations will form part of the design of the system. The bearing of the target will take the form of a digital code representing the bearing as a binary number of ( n ) bits, where ( n ) is dependent on the width of the data bus leading to the system interface, but will be at least ( n=8 ).</td>
</tr>
<tr>
<td><strong>PMMW_F_05</strong> To determine the direction of motion of the target (tracking).</td>
</tr>
<tr>
<td>The equipment should be capable of determining the change in bearing of the target in a specified period of time.</td>
</tr>
</tbody>
</table>
The tracking (direction of motion) of the target will take the form of a group of digital codes representing changes in range and bearing as a set of binary numbers each of $n$ bits, where $n$ is dependent on the width of the data bus leading to the system interface, but will be at least $n=8$.

<table>
<thead>
<tr>
<th>System interface requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMMW_S_01</td>
</tr>
<tr>
<td>CAN 2.0 or USB (to be determined).</td>
</tr>
</tbody>
</table>
### Annex B – VALIDATION FORM

#### SENSORS REQUIREMENTS VALIDATION FORM

<table>
<thead>
<tr>
<th>VALIDATION PANEL SECTION</th>
<th>Validation Expert Curriculum</th>
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<tr>
<td>Expert Name</td>
<td></td>
</tr>
<tr>
<td>Organisation Name</td>
<td></td>
</tr>
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<td>Expertise</td>
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</table>

**Sensor ID Requirements Document**

<table>
<thead>
<tr>
<th>Document Name</th>
<th>Final Version</th>
<th>YES/NO</th>
</tr>
</thead>
</table>

**Requirements Checklist**

**Functional Requirements**

| Q1 | Are the requirements uniquely identified? |
| Q2 | Are specialised terms defined in the glossary? |
| Q3 | Does a requirement stand on its own or do you have to examine other requirements to understand what it means? |
| Q4 | Do individual requirements use the terms consistently? |
| Q5 | Is the same service requested in different requirements? |
| Q6 | Are there any contradictions in these requests? |
| Q7 | If the requirements makes reference to some other facilities, are these described elsewhere in the document? |
| Q8 | Are related requirements grouped together? If not, do they refer to each other? |

**System Interface Requirements**

| Q1 | Are the requirement uniquely identified? |
| Q2 | Are specialised terms defined in the glossary? |
| Q3 | Does a requirement stand on its own or do you have to examine other requirements to understand what it means? |
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| Q5 | Is the same service requested in different requirements? |
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| Q7 | If the requirements makes reference to some other facilities, are these described elsewhere in the document? |
| Q8 | Are related requirements grouped together? If not, do they refer to each other? |
### Main Issues

<table>
<thead>
<tr>
<th>MI1</th>
<th>Requirements Clarification</th>
</tr>
</thead>
<tbody>
<tr>
<td>MI2</td>
<td>Missing Information</td>
</tr>
<tr>
<td>MI3</td>
<td>Requirements conflict</td>
</tr>
<tr>
<td>MI4</td>
<td>Unrealistic requirements</td>
</tr>
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</table>

### General Issues

<table>
<thead>
<tr>
<th>GI1</th>
<th>Understandability</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI2</td>
<td>Redundancy</td>
</tr>
<tr>
<td>GI3</td>
<td>Completeness</td>
</tr>
<tr>
<td>GI4</td>
<td>Ambiguity</td>
</tr>
<tr>
<td>GI5</td>
<td>Consistency</td>
</tr>
<tr>
<td>GI6</td>
<td>Organisation</td>
</tr>
<tr>
<td>GI7</td>
<td>Conformance to Standards</td>
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<td>GI8</td>
<td>Traceability</td>
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### Problem List

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### Agreed Actions

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### VALIDATION RESULTS

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<table>
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### SENSORS DEVELOPERS SECTION

#### Answers to the Requirements Checklist

##### Functional Requirements

<table>
<thead>
<tr>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
<th>Q5</th>
<th>Q6</th>
<th>Q7</th>
<th>Q8</th>
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</table>

##### System Interface Requirements

<table>
<thead>
<tr>
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<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
<th>Q5</th>
<th>Q6</th>
<th>Q7</th>
<th>Q8</th>
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</table>

##### Answers to the Main Issues

<table>
<thead>
<tr>
<th>MI1</th>
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<th>MI4</th>
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##### Answers to the General Issues

<table>
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<th>GI2</th>
<th>GI3</th>
<th>GI4</th>
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**Answers to the Agreed Actions**

<table>
<thead>
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<th>#</th>
<th>Sensors Developers Comments</th>
</tr>
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<td>2</td>
<td></td>
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<tr>
<td>...</td>
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</tbody>
</table>
Annex C – TLS STANDARD

TLS is a German standard guideline on traffic data acquisition for rural road facilities. The TLS mainly refers to specifications of vehicle classification and the required precision in the measurement of traffic flow parameters. The respective vehicle categories are listed according to the basic vehicle categories, as shown in the following table 3:

<table>
<thead>
<tr>
<th>Vehicle class</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powered two-wheeler</td>
<td>Powered two-wheeler, also with sidecar, no bicycles, no motored</td>
</tr>
<tr>
<td></td>
<td>bicycles</td>
</tr>
<tr>
<td>Passenger car</td>
<td>Passenger cars ranging from compact car to limousine, incl. off-</td>
</tr>
<tr>
<td></td>
<td>road vehicles</td>
</tr>
<tr>
<td>Van</td>
<td>Delivery truck ≤ 3.5t</td>
</tr>
<tr>
<td>Passenger car with trailer</td>
<td>Vehicles up to 3.5t with trailer (incl. vans)</td>
</tr>
<tr>
<td>Truck</td>
<td>&gt; 3.5t</td>
</tr>
<tr>
<td>Truck with trailer</td>
<td>Freight vehicle &gt; 3.5t with trailer</td>
</tr>
<tr>
<td>Artic</td>
<td>All artic</td>
</tr>
<tr>
<td>Bus</td>
<td>Vehicles with more than 9 seats for conveyance of passengers,</td>
</tr>
<tr>
<td></td>
<td>also with trailer</td>
</tr>
<tr>
<td>Unknown vehicle type</td>
<td>All vehicles, where the vehicle type was not identified or which</td>
</tr>
<tr>
<td></td>
<td>does not belong to another group</td>
</tr>
</tbody>
</table>

Table 15. Vehicle classes according to TLS

A single vehicle classification according to the TLS Standard is shown in the Table 4.

<table>
<thead>
<tr>
<th>Classification group</th>
<th>Vehicle category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 + 1</td>
<td>UVT Motor vehicle</td>
</tr>
<tr>
<td>2 + 1</td>
<td>UVT Passenger car-like</td>
</tr>
<tr>
<td>2 + 1</td>
<td>UVT Truck-like</td>
</tr>
<tr>
<td>5 + 1</td>
<td>UVT PC</td>
</tr>
<tr>
<td>5 + 1</td>
<td>UVT PC with trailer</td>
</tr>
<tr>
<td>5 + 1</td>
<td>UVT Truck</td>
</tr>
<tr>
<td>5 + 1</td>
<td>UVT Truck with trailer</td>
</tr>
<tr>
<td>8 + 1</td>
<td>UVT PTW</td>
</tr>
<tr>
<td>8 + 1</td>
<td>UVT PC Van</td>
</tr>
<tr>
<td>8 + 1</td>
<td>UVT PC with trailer</td>
</tr>
<tr>
<td>8 + 1</td>
<td>UVT Truck</td>
</tr>
<tr>
<td>8 + 1</td>
<td>UVT Truck with trailer</td>
</tr>
<tr>
<td>8 + 1</td>
<td>UVT Artic</td>
</tr>
</tbody>
</table>

Table 16. Vehicle classification according to TLS