Inventory and assessment of commercially available blind spot monitoring systems

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SWOV

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Prevent crashes
Reduce injuries
Save lives

Report documentation

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Summary

Shell Global Solutions International B.V. has commissioned SWOV Institute for Road Safety Research to create a combined inventory and qualitative comparison of commercially available Blind Spot Monitoring Systems (BSMSs) for buses, heavy goods vehicles and other large mobile equipment; out of an interest to equip their fleet with such systems. In addition, Shell requested an overview of measures other than BSMSs to mitigate blind spot related risks.

Research method

In order to perform a comprehensive inventory, lists of search terms and qualitative evaluation criteria were defined on the basis of literature and regulations. The resulting search terms were combined into a series of search queries which were presented to the Google search engine (cf. the project proposal). Eighty-three systems were initially found. For these systems, documentation was collected and/or requested directly from manufacturers. After further inquiries and evaluation of obtained documentation, 60 systems by 33 manufacturers were ultimately deemed suitable for further consideration. We described the properties of each system following a template of qualitative evaluation criteria, and aggregated the data in a database.

The aggregated data were evaluated in terms of completeness and general data quality. Although the Operational Design Domain of systems was apparent, considerable differences were observed between manufacturers and systems in terms of available data on System Implementation. Hardly any data were available on detection performance (e.g., false alarm rate, proportion of missed targets) and usability, making comparisons of Scientific Validity impossible. Quotes were obtained for 25 systems. Ultimately, the proportion of available observations permitted a ranking scheme for 7 system properties, namely: whether the system was (1) suitable for detection of vulnerable road users, whether it was (2) triggered (i.e., operational specifically under a predefined set of circumstances), whether it was (3) compliant with specific regulations, (4) unit costs, and, more specifically regarding the sensor(s), the (5) Ingress Protection rating, the (6) size of the Field of View, and (7) the range covered by the system.

Each system was ranked on the basis of each of these properties, in so far as the data were present. When data for a given property were not available, the system was ranked last for that particular property. The ranks were summed to obtain a total score (i.e., a ‘sum of ranks’) and systems were then ordered from best to worst based on this ranking.

Considerations

Apart from the method to rank systems included in the inventory, there are additional considerations to either favour certain systems, or to preclude them from application. These considerations are:

- Given an existing fleet, it is not feasible to replace all vehicles. This means that OEM systems that are only available for new vehicles were not selected for ranking.

- For systems that warn a driver but do not intervene, responsibility ultimately remains with the driver. Therefore, intervening systems may be preferred. However, it was found that these do not exist as retrofit solutions, presumably because adequate performance cannot be guaranteed when systems are installed by 3rd parties.
- Finally, a system that monitors the entire surround rather than a specific portion is likely to provide a higher degree of safety. Therefore, integrated solutions or single manufacturers that provide solutions to monitor all directions are preferable.

Top ranking BSMSs

Ideally, one makes use of detection performance (e.g., false alarm rate, proportion of missed targets) to rank systems in terms of crash prevention performance. However, data on detection performance were rarely provided. Therefore, sensor specifications (e.g., field of view, range) were used as proxy, in addition to several other properties described above. Taking the above considerations into account, the following systems came out on top:

- Overall, the best ranked system is the Autel Blind Spot Assist (*Appendix E.1.1*). However, this system is suitable only to monitor objects in the vehicle's lateral blind spots.
- The eXia Active Sideguard system (*Appendix E.14.1*) is among the top three for all viewing directions. However, this system is rather exotic, in that the sensor technology (monitoring the electric field) is not used by any other manufacturer. We do not know how well this system works in practice (scientific validity).
- The next-best multi-directional solution using more common radar technology is the Sensata PreView Sentry (*Appendix E.27.2*). Another advantage of choosing this particular manufacturer could be the availability of variations of this system (see *Appendix E.27*)
- The best ranking multi-directional camera system is the oToGuard system by oToBrite. This is a single integrated solution to monitor all directions, which also features an in-cabin camera to monitor the driver, and which is compliant with multiple UNECE regulations (*Appendix E.22.2*).

Inventory of non-BSMS related measures

SWOV reports and fact sheets were used for an inventory of non-BSMS related measures. These sources mainly focus on blind spots directly to the right and in front of the cabin of HGVs, in interaction with cyclists and to a lesser extent pedestrians. Three types of measures were derived: 1) measures to support the driver (e.g., education, safety culture, blind spot mirrors, cabin design, road-side mirrors), 2) measures to separate HGVs and other road users in time and space (e.g., system changes, time windows, route choice, intersection design), and 3) measures to support other road users (e.g., signage, education). The consulted literature did not provide scientific evidence on the effectiveness of these measures for traffic safety. The transferability of these measures to other blind spots is discussed. Driver education and safety culture of companies relating to blind spot situations may help in all blind spot scenarios. Strategically placed blind spot mirrors at dedicated areas for collecting or delivering goods can help reduce the blind spot behind the vehicle. When working vehicles are manufactured or bought, it is wise to consider optimising the direct view around the vehicle as much as is possible. Working with relatively safe time windows to drive with HVGs will reduce all blind spot problems to a degree. Safer routes and intersection measures are likely restricted to interactions with vulnerable road users. The use of special time windows and safe routes can be applied to the private premises of companies (e.g., ban driving with HGVs where and when co-workers walk during lunchtime).

Conclusions

In general, it was found that systems using ultrasonic technology were suitable mostly for short-range, low-speed manoeuvring, whereas ultrasonic and camera systems are also suitable for longer-range and motorway use. When taking into account that a modular system suitable to monitor all directions may offer the most comprehensive solution, we find that a particular system using unique technology that monitors the electric field ranks best. However, somewhat lower, but nonetheless comparable, rankings were found for a more traditional camera system and radar system. Ultimately, it should be noted that although information could typically be retrieved on system Operational Design Domain and Implementation, reliable indications of their actual detection performance were only available for a single system, and performance for this system was limited to approximately 50% detections. Ecologically valid empirical studies on detection performance may help improve the discrimination of BSMSs.

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1 Introduction

SWOV Institute for Road Safety Research has been commissioned by Shell Global Solutions International B.V. to create an inventory and qualitative comparison of commercially available Blind Spot Monitoring Systems (BSMSs) for buses, heavy goods vehicles and other large mobile equipment. This introduction describes the background and organisation of the inventory.

Crashes involving trucks and other road users tend to have serious consequences for the other road users (e.g., Jansen & Varotto, 2022), especially if the other road users are Vulnerable Road Users (VRUs), such as pedestrians, cyclists, and motorcyclists. Often, crashes are due to the driver being unaware of a road user being present in so called *blind spots* around the vehicle. A blind spot is an area in the immediate surround of the vehicle which is not directly visible to the driver. In order to contribute to crash prevention, vehicles may be designed so that the sizes of blind spots are minimized and/or made visible through additional means, such as mirrors or camera-display feeds. However, given that drivers have a limited Field-of-View and attentional resources, the occurrence of blind-spot related incidents cannot be ruled out. As such, there is a need for additional safety mechanisms.

Advanced Driver Assistance Systems (ADAS) that aid drivers in the driving task have been introduced in various vehicle segments in recent years. These systems make use of technologies to provide, for example, intelligent speed or lane-keeping assistance, to monitor driver fitness and to provide warnings (e.g., in case of drowsiness or distraction) and to perform emergency interventions such as braking or steering. Assistance systems are also used to minimize the risk of crashes between trucks and VRUs. Similarly, technologies that monitor blind spots and warn drivers of objects and/or VRUs present in blind spots are gradually introduced in new vehicles.

SWOV Institute for Road Safety Research has been commissioned by Shell Global Solutions International B.V. to create an inventory and qualitative comparison of commercially available Blind Spot Monitoring Systems for buses, heavy goods vehicles and other large mobile equipment (e.g., mining vehicles). As Blind Spot Monitoring Systems, we consider any system that actively warns drivers of objects and road users present in blind spots around the vehicle. The scope of this inventory includes systems integrated in new vehicles, as well as retrofit options. In addition, we review alternative measures to counter the risks related to blind spots by providing support to drivers and VRUs and by infrastructure design choices.

1.1 Reading guide

Chapter 2 defines a set of search terms and eligibility criteria for systems to be included in the inventory, as well as a set of evaluation criteria that operationalise overall system quality.

In *Chapter 3*, we provide a ranking of the systems that could be included in the inventory. We consider the quality of the data and provide descriptive statistics of a number of key properties, after which we propose a method to rank systems given limited availability of data. Using this method, we then rank systems and consider which systems could be considered most suited for a number of practical scenarios.

In *Chapter 4*, we provide a separate overview of alternative measures to counteract the risks of blind spots. These include other methods to support the driver, methods to reduce the frequency at which VRUs and vehicles are in close vicinity, and methods to support the VRUs themselves.

Finally, in *Chapter 5* we review the findings of this study and provide a number of recommendations.

2 Research method

Based on regulations relating to BSMSs and on the project scope, we propose a series of queries to search for commercially available systems; provided either by OEMs or as retrofit options. The purpose of the review of regulations and search for systems is to establish a (preliminary) set of terms and parameters that allow identification of systems that are relative to the present review, and quantification of the quality of these systems, thus also allowing qualitative comparison.

2.1 System inventory

An inventory of systems was obtained in four steps. First, a search query was constructed based on a list of search terms, and the search queries were entered in Google search (*Section 2.1.1*). Second, the results of the search queries were pre-compared to a set of eligibility criteria (e.g., for as far as this was possible with a quick scan of the webpages) to compile a list of candidate systems (*Section 2.1.2*). Third, information on each system was requested from the relevant companies and/or obtained from their webpages (*Section 2.1.3*). Fourth, the information was used to determine whether a candidate system was indeed eligible, and if so, the information was entered into an Excel template (*Section 2.2*).

2.1.1 Search terms, query, and procedure

Ideally, the search would yield an exhaustive list of all available blind spot detection systems, but would exclude general information or other tangentially related results. Legislation described in *Appendix A*, as well as an exploratory search query resulted in a set of search terms listed in *Table 2.1*.

Table 2.1. Overview of search terms.

Keyword group	Viewing device class	Search terms
Indirect viewing devices	-	Any of: 'Blind spot', 'Blind-spot', 'Blind zone' Combined with any of: 'Warning system', 'Monitoring system', 'Detection system', 'Assist', 'Information system', 'Intervention', 'Collision'
Location: side	II, IV, V	'Side blind zone alert', 'Side-view assist', 'Side assist', Side object detection'
Location: rear	I	'Rear automatic braking', 'Reverse automatic braking', 'Rear parking assist', 'Rear cross traffic alert', 'Reversing detection', 'Rear object detection'
Location: front	VI	'Front blind spot', 'Front blind zone', 'Front blind-spot', 'Moving off information system'
Vehicle	-	'Heavy goods vehicle', 'Truck', 'Bus', 'Coach', 'Crane', 'Mining', 'Front loader', 'Excavator'

Search queries were constructed by combining search terms of the first four keyword groups in *Table 2.1* with search terms in the 'Vehicle' keyword group. The logical operator 'OR' was used to combine different search terms within a keyword group, and the logical operator 'AND' was used to combine different keyword groups. The prefix 'intitle:…' was at times used to limit the number of search results to a manageable size. For example, the following search query was used to find various spellings of 'blind spot warning systems' for trucks, heavy goods vehicles, and buses:

intitle:"blind spot warning system" OR intitle:"blind-spot warning system" OR intitle:"blind zone warning system" AND ("truck" OR "heavy goods vehicle" OR "bus")

A total of 20 searches was performed in January 2023. See *Appendix B* for a complete description of the search queries. The search queries listed in *Appendix B* were performed using the Google search engine in a Firefox (version 111.0.1) browser tab. A new window of Firefox's 'private mode' was used for each new search query to minimize the influence of cookies based on prior internet activity (e.g., clicking on results, searching for additional information) on the results shown for a new search query.

If a result redirected to another webpage, the most recent page was used. At times, the result concerned a news item on a certain system. In such cases, a separate search was performed to find the website of the system manufacturer.

After examining a certain number of (pages with) results, Google's search engine typically displayed the following message at the bottom of the page: *"In order to show you the most relevant results, we have omitted some entries very similar to the [number] already displayed."* The search within the corresponding query was stopped when this message was displayed.

2.1.2 Eligibility criteria

The following criteria had to be met to consider a search query result as a candidate blind spot detection system:

- A system is described, consisting of at least an input module (e.g., a sensor), an output module (e.g., a display) and an algorithm which detects objects and informs the driver about object presence. Modular systems exist, in which input and output modules can be combined. For such systems, a single webpage may not contain all physical components. The result was included if at least the *functioning* of the modular system components is described.
- The result of the search query concerns the original manufacturer of the system.
- The system is intended for at least one of the following vehicles: heavy goods vehicle, bus, mining vehicle, construction vehicle.

The following list of criteria resulted in exclusion from the inventory:

- The result describes a patent. Patents do not require a fully working implementation, and may cover several different implementation concepts to secure a market advantage. This reduces the likelihood of unambiguously coding the implementation of systems covered by industry patents; a necessity in the present inventory.
- The result concerns a system listed by Amazon, Alibaba, and similar suppliers. We only look at original manufacturers.
- The result concerns a video, without text (e.g., Youtube videos).
- Results concerning posts on an internet forum were often excluded. Discussions are typically about the use of these systems in general. If the first post clearly identifies the name of a blind spot detection system, the name may be used as a separate search to find the original manufacturer. Internet forums discussing passenger cars and pickup trucks were excluded from review.
- The result concerns an academic paper, in which a system is proposed, but the system is not yet on the market.

- The output module of the system is only located outside the cabin to warn other road users (e.g., external HMIs).
- Firefox marks the corresponding webpage as a security risk.
- The result leads to a website that is undergoing maintenance.
- The result concerns a website describing how blind spot monitoring systems work.[1]
- The result concerns a system intended for *testing* blind spot monitoring systems (e.g., it does not describe a blind spot monitoring system).[2]
- The result is not in English or Dutch.
- The result only describes products marketed for passenger cars or pickup trucks, without any explicit (e.g., text) or implicit (e.g., imagery) reference to heavy goods vehicles, buses, or mining/construction vehicles.
- The result concerns a search query within another search engine (e.g., Bing). Only searches with the Google search engine were performed.
- The results concern a post on social media - it is often required to log in to access content on social media platforms.

Due to limited information on websites, it was not always possible to determine if all inclusion criteria were met and if none of the exclusion criteria applied. These results, too, were marked as candidate systems. The above procedure yielded a set of 83 candidate systems by 42 companies. A final evaluation on eligibility was performed by collecting further information on the systems.

2.1.3 Collecting information on systems

A cover letter with an information request was prepared (see *Appendix D*), as well as an (empty) Excel sheet listing the information items we ultimately required with a short explanation for each of the items (see *Appendix C* and *Section 2.2*) for the rationale behind the information items). The way information was collected on each system depended on the contact options of the company website:

- If the website contained an e-mail address, the cover letter and accompanying Excel sheet were sent directly using that e-mail address.
- A contact form was used if the website did not contain an e-mail address. The number of words of the contact form boxes was often limited. In such a case, a shortened version of the cover letter was entered, including the request to contact us. In case of a reply by a person (e.g., not an auto-reply that merely acknowledged our contact request), the cover letter and corresponding Excel sheet were sent.
- Phone calls were made if the website did not contain an e-mail address, nor a contact form. In the phone call, the cover letter was used to explain the background of the project, followed by the request for an e-mail address to send our cover letter and corresponding Excel sheet.

Initial information and contact requests were sent between February 21st and February 23rd. The deadline for delivery of the information was stated as 2 weeks following the date of the request. Between March 7th and March 15th all companies that had not responded were sent at least one reminder. The reminder explicitly stated the hypothetical business cases described in the cover letter. By March 27th, 12 companies had shared information with us on a total of 17 systems. The product website was used for systems manufactured by a company that did not respond to our information request. Often these websites included product leaflets and installation manuals. The final sample consisted of 64 eligible systems of 35 companies.

1. E.g., www.mycardoeswhat.org
2. E.g., www.vboxautomotive.co.uk/index.php/en/products/data-loggers/vbox-3i-adas?gclid=EAIaIQobChMI5cv3z_Lf_AIV54xoCR2XygNTEAMYASAAEgIxhvD_BwE

2.2 Evaluation criteria

Systems will be evaluated in terms of operational design domain, implementation, scientific validity, reliability, cost and availability. For all potential criteria discussed in the following, a prerequisite for actual application is that the required data are available or are made available by manufacturers. It is outside the scope of the project for SWOV to perform empirical studies on the quality of systems.

2.2.1 Operational Design Domain

Different systems can be designed with any target application in mind, which is referred to as the Operation Design Domain, or ODD. We operationalise the ODD in terms of the intended **vehicle**, the target **blind spot**, and **functional** properties such as the type of objects it is designed to detect.

Vehicles can be categorised in various ways. In official regulations, vehicles are classified in categories based on whether vehicles are primarily intended to transport goods or people, and the size of the load. We refer to these classes as **UNECE classifications**, and note these whenever manufacturers specify a system for application in these classes.
In practice, vehicles tend to be categorised on the basis of other features, notably whether they are **rigid** (e.g., a box-truck), **articulated** (e.g., tractor/trailer combinations, accordion buses), or **other vehicles** (e.g., mining, construction). Allocation of a system to either of these categories is not a mutually exclusive property, and we note applicability to either category as a dichotomous property.

Second, systems can be designed with a particular blind spot in mind. As for vehicles, regulations exist that address specific blind spots. Again, we note these as **UNECE classifications.** In practice, systems were found to be typically classified in terms of example use cases; for example, as a *Blind Spot Information/Monitoring System,* as *Moving-Off Information System,* or as *Reversing Information System* (**BSIS, MOIS, REIS**). Where mentioned in documentation, we note these classes in our inventory. Another, more general way to categorise systems is by specification of their general viewing direction, namely *forward,* to the *side (driver* or *passenger*), or rearward. We note the **monitoring direction** as well.

Third, systems can be intended specifically for the detection of **stationary or moving objects,** can be explicitly stated to be suitable for **detection of** VRUs, or to function while a driver performs a particular **manoeuvre** (e.g., turning, lane changes, reversing).

2.2.2 Implementation

Systems with any given design domain may be implemented in various ways. These technological choices affect system performance characteristics. The choice of criteria included in the present inventory is a compromise between desirable and typically available information, based on prior agreements made while defining the project scope. We specify the following classes of system properties:

General: we note the **sensor type(s)** included in the system. Typical sensor types are cameras, radar sensors and ultrasonic sensors. (Modular) systems can combine multiple sensor types. For each sensor, we also make note of the **Ingress Protection (IP) code**. Similarly, we note the IP code of the Electronic Control Unit (ECU). Finally, we note the number of sensors in the system. Where modular systems are at issue, we note the distinct possibilities in numbers of sensors.

Power system: For each system we note basic electronic characteristics, namely whether power must be provided by the vehicle or by some external power source (**vehicle/stand-alone**); system operating voltage or **voltage range, current consumption,** and/or **power consumption.**

Sensor description: manufacturers may provide various performance metrics for the sensors used in their systems. Some provide sensor performance metrics for individual sensors, whereas others provide such information, in case of a multi-sensor system, for the array of sensors. To evaluate system quality, we distinguish whether information is provided on the level of the **individual sensor vs. array.** We note the Field-of-View of the sensors (FOV; **horizontal FOV** and **vertical FOV**), along with measures of **FOV accuracy** (i.e., information on *constant errors*) and **FOV precision** (i.e., *variable errors*). These metrics are quantified in degrees of the visual field covered. Apart from the FOV, sensors also have a particular effective range. We specify this range in terms of **range width**, which is the lateral reach, from the perspective of the sensor, and the **range depth**, which is the forward reach, from the perspective of the sensor. Also, for range, we try to provide measures of **accuracy** and **precision**. These latter metrics are quantified in meters.

Object Properties: in terms of criteria on object properties that must be met in order to ensure detection, we consider the minimal size of an object, the **minimal object resolution**, in degrees of the visual field.

Human-Machine Interface: apart from performance characteristics of particularly the sensors, the efficacy of a system depends on the action taken upon detection of an object; whether the system issues a warning to the driver or intervenes (e.g., by braking; **warning vs. intervening**). In case a system issues warnings, we note the **warning type** (e.g., visual, auditory, and/or tactile) and whether or not the warnings are **staged** (i.e., issued in incremental levels of urgency); in case of an intervening system, we note the **intervention type** (e.g., braking, steering). Finally, systems may become dysfunctional for a variety of reasons. We note whether a system evaluates its own functioning and whether it includes a **malfunction indicator** for the driver.

System Integration: some systems require integration with other vehicle systems, whereas others function completely independently from the vehicle. We note this as **integrated vs. stand-alone** systems. For integrated systems, some form of **connection** is required (e.g., CAN-bus). Systems may also connect different components **wirelessly.** When this information is available, we note the type of **input** information required by a system.

Reliability: finally, we note information on system reliability, in terms of **lifetime** (hours), any required **maintenance**, and **compliance with standards**

2.2.3 Scientific Validity

Performance of a system as a whole depends not only on sensor characteristics, but also on the implemented classification algorithms that operate on the information provided by the sensor, and the efficacy of the Human-Machine Interface. To quantify classification performance, we consider information on system **sensitivity**, which is the proportion of true positive results obtained in empirical testing, thus quantifying how well a system is able to detect the true presence of anything in the blind spot. We also consider the **specificity**, which is the proportion of true negatives, or the ability to correctly note the absence of anything in the blind spot. The complement of this metric is the proportion of false positives, or *false alarms*, which are known to be detrimental to trust in a system. Where sensitivity and specificity are not exactly quantified but other **qualitative statements** on system performance are given, we note these.

Of particular relevance to valuing numbers on sensitivity and specificity is also the rigorousness of the test protocol that was used to attain these numbers. Here we consider the **number of observations** collected, which is the number of independent experimental trials conducted from which proportions of true positives and negatives are calculated. In accordance with the Law of Large Numbers, estimates of these rates are more reliable when more experimental observations are made. In addition, we note the **blind spot coverage** of empirical tests. Here, we consider whether the extent to which empirical tests cover the sensor FoV. Similarly, we evaluate whether tests were performed under different **ambient conditions**, varying e.g., lighting conditions, temperature, and background vibrations. Finally, we consider whether **usability tests** were performed with drivers, and note user perspectives on the system performance in practice.

2.2.4 Cost

In order to compare system cost, manufacturers were asked to provide quotes on unit costs for the following (hypothetical) use cases:

(1) 1,000 12m rigid trucks
(2) 10,000 16.5m tractor/trailer combinations
(3) 1,000 cranes

Because this information is typically considered confidential, any information we obtained is not made public except for three broad categories on unit cost: namely € (0-500] is categorized as '€', € (500-1000], categorized as '€€', and ≥€1000, categorized as '€€€'. If made available, a minimum order quantity (MOQ) is described.

2.2.5 Availability

To assess whether it is feasible to equip a global fleet of vehicles, we consider whether a system is available for purchase worldwide or only in particular regions (i.e., **spatial** availability), and if only regionally, which regions. We also consider **temporal** availability, which refers to the time frame within which the system can be delivered. We will also evaluate the scalability of the solution, which refers to the rate at which production can be increased, again spatially and temporally. Similar to data on unit costs, data on system availability can be considered sensitive to a company's competitive position. It is therefore presented only in a very general way.

3 System ranking

Assessments of the quality of the systems identified using the search queries described in *Chapter 2* should be based on the extent to which they prevent crashes. On the one hand, such assessments have to take into account technical features of the equipment – for mirrors these are for instance the viewing angle provided by the mirror and the direction of the mirror relative to the driver and vehicle surround; on the other hand, these assessments have to take into account the extent to which the equipment adequately informs the driver of actual hazards and its ability to avoid false alarms. In the following, we describe how a ranking of systems was produced based on the data collected in this inventory.

In order to make a comparison, we first need to distinguish between classes of systems intended for different purposes, in order not to compare apples and oranges. This is done on the basis of variables included in the 'Operational Design Domain' category of the evaluation criteria. Subsequently, we need to construct a score for each system that reflects how well it meets a set of predefined requirements, notably its performance. In the real world, system performance is quantified in terms of sensitivity and specificity to the presence of objects in blind spots, included in the 'Scientific Validity' category of evaluation criteria. This performance depends in part on the quality of sensors, but also on any subsequent processing of data provided by the sensors. Unfortunately, data on Scientific Validity were not available (except for one system) and therefore it is not possible to compare systems on these criteria. However, if it is assumed that the detection performance of any classifier improves with the quality of the sensor, then features of the sensor may be taken as a proxy for real-world performance.

To rank systems, it is essential that enough data are available. This is complicated by the fact that there is no overarching standard to describe BSIS, MOIS, REIS and other instances of BSMSs, meaning that we can only use criteria that multiple manufacturers happen to report. To make this assessment, we first provide descriptive statistics on data availability, and subsequently describe the method used to rank systems using the available data.

3.1 Data quality

The system descriptions as presented in *Chapter 3* were entered into a spreadsheet for comparative analyses. In this document, the columns correspond to the evaluation criteria laid out in *Section 2.2*, and the rows represent individual systems. The spreadsheet is available as digital information supplementary to this report.

The criteria included in the Operational Design Domain category could be determined in the majority of cases. For each criterion, the number of cases where data were not available (NA) vs. the number of complete and percentage of complete cases is presented in *Table 3.1*. Note that this table indicates whether data are available; not the percentage of yes vs. no.

Table 3.1. Percentage of systems for which the value of a given subcategory of the Operational Design Domain category of system properties could be determined.

Operational Design Domain	NA	n complete	% complete
Rigid vehicles (y/n)	8	52	86.7
Articulated vehicles (y/n)	23	37	61.7
Other vehicles (y/n)	38	22	36.7
UNECE vehicles classes	25	35	58.3
System class	45	15	25.0
Monitoring direction	11	49	81.7
UNECE blind spot classes	51	9	15.0
Object detection type	13	47	78.3
VRU detection (y/n)	15	45	75.0
For specific manoeuvres	15	45	75.0

Criteria from the Implementation category were not reported consistently for all systems; in fact, no complete set of data was obtained for any system included in the inventory. For each criterion, the number of cases where data were not available (NA) vs. the number of complete and percentage of complete cases is presented in *Table 3.2*. Note again that this table indicates whether data are available; not the percentage of yes vs. no.

Table 3.2. Percentage of systems for which the value of a given subcategory of the Implementation category of system properties could be determined.

Implementation	NA	n complete	% complete
Sensor type(s)	2	58	96.7
IP rating sensor	27	33	55.0
IP rating ECU	40	20	33.3
Number of sensors	10	50	83.3
Power source	36	24	40.0
Operating voltage	21	39	65.0
Current consumption	38	22	36.7
Power consumption	45	15	25.0
Sensor or array description	19	41	68.3
FoV-horizontal	25	35	58.3
FoV-vertical	36	24	40.0
FoV accuracy	52	8	13.3
FoV precision	55	5	8.3
Range width	31	29	48.3
Range depth	15	45	75.0
Range accuracy	47	13	21.7
Range precision	50	10	16.7
Minimal object resolution	50	10	16.7
Warning vs. Intervening	5	55	91.7
Warning type	4	56	93.3
Staged warnings	19	41	68.3

Intervention type	58	2	3.3
Malfunction indicator	36	24	40.0
Integrated vs. Stand-alone	23	37	61.7
Data connection	32	28	46.7
Wireless (y/n)	25	35	58.3
Input signals	22	38	63.3
Lifetime	51	9	15.0
Maintenance	45	15	25.0
Compliance with UNECE R151, R158, or R159	54	6	10

Data on scientific validity were rarely available. Numbers on sensitivity were provided for 6 out of 60 systems (10%); numbers on specificity for 3 out of 60 systems (5%). For 25 out of 60 systems (41.67%) quotes were obtained, or unit costs were found in online sources.

3.2 Descriptive statistics

The majority of systems included in the inventory are available only as a retrofit solution 35 (out of 60) systems, 6 systems are only available as OEM solutions, and 9 systems are available as both OEM and retrofit solutions. For 10 systems, there was no information on this variable (NA).

Systems were mostly intended for rigid vehicles (51 ‘yes’; 1 ‘no’; 8 NA), followed by articulated vehicles (32 ‘yes’; 5 ‘no’; 23 NA), and other (construction/mining) vehicles (19 ‘yes’; 3 ‘no’; 38 NA). For monitoring the sides of the vehicle, 41 systems were available; 15 to monitor the front and 27 to monitor the rear. These categories were not mutually exclusive. There were 15 systems that monitor all sides of the vehicle, and 4 systems that monitor the side and rear. There were 22 systems that only respond to moving objects; 2 systems only to stationary objects; and 23 systems to both stationary and moving objects. There were 40 systems that were specifically specified as detecting VRUs; 5 systems were not intended for detection of VRUs, and for 15 systems there were no data on this variable.

Given the practical unavailability of scientific validity data, sensor quality was considered as a proxy for system performance. The inventory included 15 (out of 60) ultrasonic systems; 31 radar systems; 11 camera systems and 1 system that monitors the electric field. For 2 systems, the sensor class could not be determined. Sensor quality was operationalised in terms of IP rating, sensor FoV and range. Accuracy, precision, and minimal object resolution were not considered, because data were not sufficiently available. IP rating was found to be high for practically all systems, thus not providing much discriminative value. It was however noted that performance differed considerably between the sensor classes. This is visualised in *Figure 3.1* and *Figure 3.2*, for FoV and range, respectively.

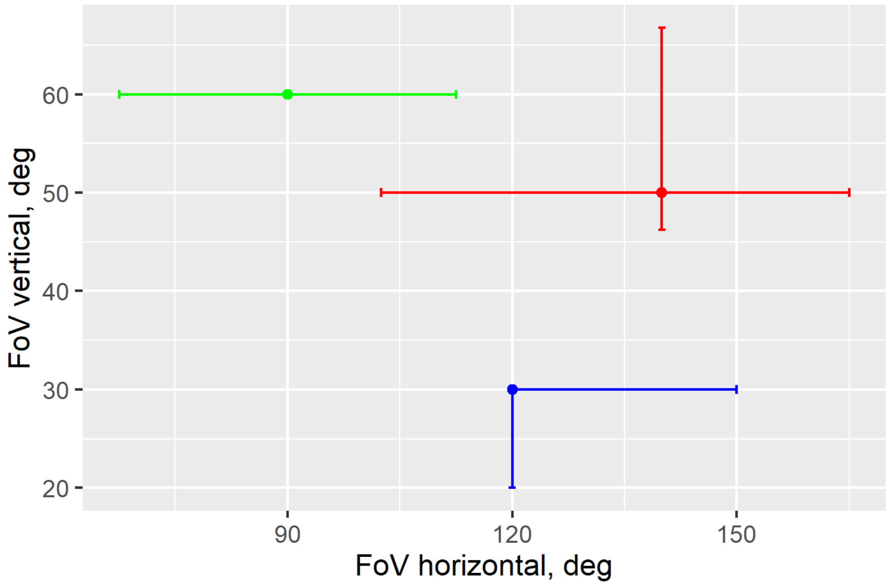

Figure 3.1. Horizontal and vertical FoV, in degrees, for the three main classes of sensors: camera (red); ultrasonic (green); and radar (blue). Dots represent the medians; error bars the 1st, ,to 3rd quartiles.

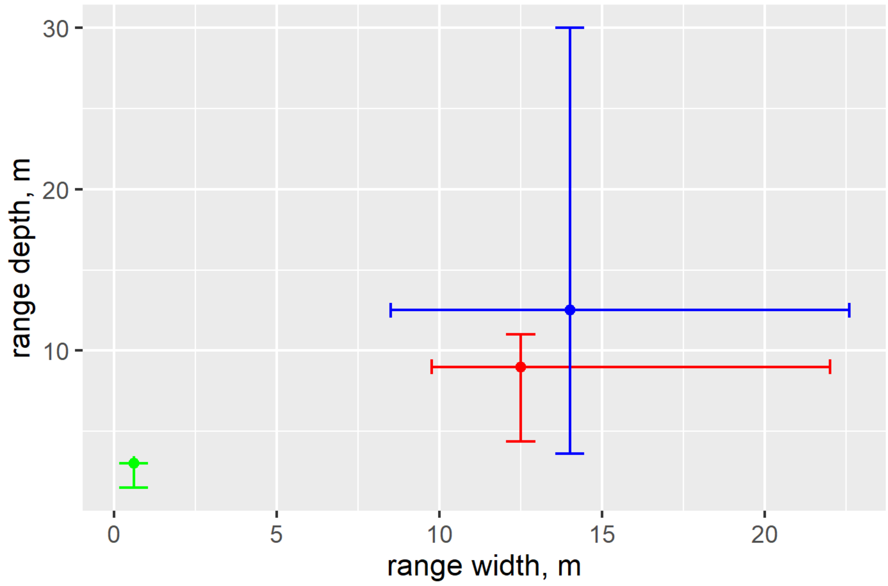

Figure 3.2. Width and depth of sensor range, in meters, for the three main classes of sensors: camera (red); ultrasonic (green); and radar (blue). Dots represent the medians; error bars the 1st to 3rd quartiles.

In addition to the noted differences in performance, unit costs also differed notably between systems of different classes: the median price for ultrasonic systems was €321.60 (1st quartile: €271.57, 3rd quartile: €352.77); for radar systems €500.00 (1st quartile: €473.17, 3rd quartile: €1070.43); and for camera systems €1626.67 (1st quartile: €678.13, 3rd quartile: €2225.83). Considering FoV and range vs. unit cost, and taking into account that providing a camera feed to the driver may not be strictly necessary to prevent crashes, these statistics suggest that ultrasonic sensors may be preferred for short-range/low-speed manoeuvring, whereas radar systems may be preferred for motorway driving (see also *Chapter 5*).

3.3 Quality based system ranking

To ensure that rankings and classifications could indeed be made, it was necessary to express the values per individual property numerically and in a uniform way. This means that nuances included in the text (*Appendix E*) could not be included in the spreadsheet. The following rules were applied to simplify data, and to convert it to a form convenient for subsequent processing:

Operational Design Domain

- Systems were classified as OEM, retrofit or both;
- Suitability for equipping different categories of vehicles (rigid, articulated, off-motorway) was stated as y/n;
- Viewing direction was reduced to three main categories: front, side and rear. These were each represented by a dummy variable which has the value 1 if the system is suitable for a given viewing direction, 0 when it is not, and left empty when there are no data;
- The types of objects detected were categorised as stationary and/or moving.

Implementation

- Sensors were attributed to one of three main classes, namely ultrasonic sensors, radar sensors or camera sensors, with one exception, namely 'electric field', for a unique system that uses a sensor that monitors disturbances of the electric field. A number of systems combine sensor types. To attribute these to one of the main classes, we used the following rules: (1) if a camera is used to provide a view to the driver, but no processing (i.e., classification) is performed on the camera image, then camera features are ignored; (2) if a system processes data from multiple classes of sensors, then the class with the most favourable features is reported, along with the associated features;
- If a system features multiple sensors, and performance metrics are given for individual sensors, then an assessment was made on a case-by-case basis whether performance metrics are complementary and can be added. We aim to compare systems based on overall performance features rather than by features of individual components;
- For radar systems with a dual antenna, the highest values for range and FoV were used;
- Systems that are operational only when particular conditions defining their operational design domain (e.g., active while reversing or turning) are met likely have fewer false alarms, which is beneficial for user acceptance. We include a variable for triggered systems which reflects whether the system is known to be activated in specific conditions. This is evaluated based on whether the system is (1) integrated with the vehicle (e.g., over CAN-bus), and (2) whether it uses inputs from the vehicle such as a reversing signal or turn signal.

Unit Cost

- Quotes for the three different business cases were typically dependent on the number of sensors required to cover a certain area rather than vehicle class per se. Some manufacturers indicated that the unit cost would drop for larger orders, but not all. To deal with variability in unit costs introduced by these factors, we calculated an average approximate cost over the quotes provided for each system.

The following criteria were found relevant and suitable to use for an objective ranking:

1. **VRU detection:** one of the main requirements for (several types of) BSMSs is to detect VRUs. Therefore, when a BSMS is known to respond to VRUs, this is added to the system score.
2. **Ingress Protection (IP) rating**: although various standards and compliances can be found in documentation, the IP rating is fairly standard. The IP rating consists of "IP" followed by a series of digits/letters, which indicate solid-particle ingress protection; liquid ingress protection; and an optional letter that holds some additional information. Solid-particle protection ratings vary in 7 discrete levels, starting at 0; liquid protection varies in 11 discrete levels, starting at 0. We attribute a score to the IP rating by dividing both numbers of the rating by their respective number of levels -1 (thus normalising them), and summing these values. IP ratings are usually given for sensors and ECU separately. Since sensors tend to be mounted outside the vehicle and are exposed to tougher conditions than the ECU, we focus on the sensor rating. When more than one IP rating is specified for a given sensor, we use the most favourable rating;
3. **Horizontal and vertical FoV:** The horizontal and vertical FoV possibly range between 0-360 degrees. A larger FoV means more coverage, which is preferable;

4. **Range, or depth and/or width of the FoV:** a larger range is preferable. For some systems, the sensor FoV could in actuality not be properly described as a single cone. In these cases, datasheets and manuals typically describe the FoV in different ranges.
5. **UNECE compliance:** When a system is stated as compliant with UNECE regulations R151, R158, and/or R159, we assume it meets a certain minimum quality standard. Therefore, compliance with UNECE regulations is considered a plus;
6. **Triggered systems:** systems that are activated only in certain conditions may reduce the false alarm rate and thereby increase user acceptance. When systems are known to be activated in specific conditions, this is added to the system score.
7. **Cost:** even though not many quotes were obtained, cost is a major factor when equipping a large fleet with BSMSs. Therefore, costs were taken into account where data were available. We took the average unit cost over the three business cases, and converted all currencies to Euros using the appropriate conversion rate reported by Google at March 20, 2023 (£1=€1.14; $1=€0.93). More affordable solutions are preferred, and therefore the effect of cost is negative. Because quotes were provided as confidential information, it is reported only in coarse bins: €(0, 500] is shown as '€'; €(500,1000] as '€€' and; €(1000,10000] as '€€€'.

To generate a ranking of systems while dealing with partial data and variables with different ranges, some issues must be considered: first, the relative importance of different variables must be determined. This depends on the practical requirements of a system. Given that the present inventory is exploratory, it was decided to use a uniform weighting. In practice, relative importance can be expressed as a weighting for each variable; this weighting was thus effectively set to 1 for each variable. Second, different variables can take on values in different ranges. For instance, FoV ranges between 0-360, while whether or not a system detects VRUs is a dichotomous (0/1) property. To deal with this, data can be converted to a common range. We initially considered *z-scoring* variables. This method consists of subtracting the mean value of a variable from each observation and dividing the result by the variable standard deviation; resulting in variables with a 0 mean and standard deviation of 1. However, given that a z-score of 0 reflects average performance and that variables with missing data would add a 0 to an overall system score, this method would result in systems for which no data are available to be ranked as average. This was considered undesirable. Instead, we calculated system score as a "sum of ranks": (1) we rank each variable from best to worst, with missing values being attributed the lowest ranking, and then (2) normalize the ranks, such that ranks for all variables take on values within the range 0-1, corresponding from missing to best, regardless of the number of ties. Finally, (3) we sum the ranks and order them from high (best) to low. In this scheme, a system for which no data were obtained would rank at the bottom of the list rather than in the middle (as would have been the case when ranking by a z-score scheme).

These considerations and procedure described above result in the rankings given in *Table 3.3*, *Table 3.4*, and *Table 3.5* in the following sections. Rankings are split by viewing direction, in order to facilitate an overview of companies that can cater to multiple-use cases. Note that ranks are specific to a system, so that a system suitable for monitoring multiple directions receives the same absolute rank in each category. In general, IP ratings show very little variance and almost all systems in the aforementioned tables are capable of VRU detection. In addition, all systems with a sidewards monitoring direction are triggered (typically as part of a staged warning design). Consequently, sensor properties, UNECE compliance, cost, and data availability are the discerning features for the systems listed in *Tables 3.3-3.5*.

3.3.1 Forward

Table 3.3. Ranked overview of top 10 systems intended for monitoring blind spots in front of the vehicle, along with evaluation criteria (in grey columns only). For definitions, please refer to Section 4.2. OEM vs. triggered is '0' when OEM-only; '1' when retrofit-only; and '2' when both.

Manufacturer	System name	OEM vs. retrofit	Intervening (y/n)	Sensor class	IP rating score	FoV horizontal (°)	FoV vertical (°)	Range depth (m)	Range width (m)	Triggered (y/n)	UNECE compliance (y/n)	VRU detection (y/n)	Approximate cost	Rank
eXia	Active Sideguard	1	n	electric field	2	360	110	2.5	16	y		y	€€€	3
Sensata	PreView Sentry	2	n	radar	2	150	20	30	8	y		y	€€€	7
oToBrite	oToGuard	2	n	camera	2	360				y	y	y	€€€	8
Sensata	PreView SentryX	2	n	radar	2	120	20	30	8	y		y	€€€	10
Advantech	TREK-154	1	n	camera	2	180		12			y	y	€€€	14
Roadefend Vision Technologies	AI-5-E	1	n	camera	1.9	85	50			y		y		17
Brigade	Ultrasonic Obstacle Detection	1	n	ultrasonic	1.9	90	60	2.5				y		25
Durite	Blind Spot Detection System	1	n	ultrasonic	1.9	90	60	1.5		y				26
Stoneridge-Orlaco	Orlaco RadarEye	1	n	radar		70	11	4	20			y		32
Roadefend Vision Technologies	AI-8-BOXHP	1	n	camera	1.9	85	50					y		33

3.3.2 Side

Table 3.4. Ranked overview of top 10 systems intended for monitoring blind spots to the sides of the vehicle, along with evaluation criteria (in grey columns only). For definitions, please refer to Section 4.2. OEM vs. triggered is '0' when OEM-only; '1' when retrofit-only; and '2' when both.

Manufacturer	System name	OEM vs. retrofit	Intervening (y/n)	Sensor class	IP rating score	FoV horizontal (°)	FoV vertical (°)	Range depth (m)	Range width (m)	Triggered (y/n)	UNECE compliance (y/n)	VRU detection (y/n)	Approximate cost	Rank
Autel	Blind Spot Assist	1	n	radar	2	180		4.5	80	y	y	y		1
oToBrite	oToBrite BSIS	2	n	camera	2			4.75	43	y	y	y	€	2
eXia	Active Sideguard	1	n	electric field	2	360	110	2.5	16	y		y	€€€	3
CandidTech	Bus all-around blind spot detection system	1	n	radar	1.8	120	30	20	50	y		y		4
Rostra Accessories	Blind spot detection system 3.0	1	n	radar	2	70	30	15	4.5	y		y		6
Sensata	PreView Sentry	2	n	radar	2	150	20	30	8	y		y	€€€	7
oToBrite	oToGuard	2	n	camera	2	360				y	y	y	€€€	8
Continental	RightViu	2	n	radar	2	120	20	4	14	y		y	€€	9
Sensata	PreView SentryX	2	n	radar	2	120	20	30	8	y		y	€€€	10
Sensata	PreView Side Defender II	2	n	radar	2	150	20	3	12	y		y	€€€	11
Stoneridge-Orlaco	Orlaco Side Eye	1	n	radar	2	118	78	3	12	y		y	€€€	12

3.3.3 Rear

Table 3.5. Ranked overview of top 10 systems intended for monitoring blind spots behind the vehicle, along with evaluation criteria (in grey columns only). For definitions, please refer to Section 4.2. OEM vs. triggered is '0' when OEM-only; '1' when retrofit-only; and '2' when both.

Manufacturer	System name	OEM vs. retrofit	Intervening (y/n)	Sensor class	IP rating score	FoV horizontal (°)	FoV vertical (°)	Range depth (m)	Range width (m)	Triggered (y/n)	UNECE compliance (y/n)	VRU detection (y/n)	Approximate cost	Rank
eXia	Active Sideguard	1	n	electric field	2	360	110	2.5	16	y		y	€€€	3
CandidTech	Bus all-around blind spot detection system	1	n	radar	1.8	120	30	20	50	y		y		4
Rostra Accessories	Blind spot detection system 3.0	1	n	radar	2	70	30	15	4.5	y		y		6
Sensata	PreView Sentry	2	n	radar	2	150	20	30	8	y		y	€€€	7
oToBrite	oToGuard	2	n	camera	2	360				y	y	y	€€€	8
Sensata	PreView SentryX	2	n	radar	2	120	20	30	8	y		y	€€€	10
Brigade	Backsense	1	n	radar	2	120	12	30	10			y		13
Advantech	TREK-154	1	n	camera	2	180		12			y	y	€€€	14
Rear View Safety	Waterproof Backup Sensor Reversing System		n	ultrasonic	1.9	51	62	1.4	0.6	y		y	€	16
Roadefend Vision Technologies	Smart video monitoring and alarm system AI-5-E	1	n	camera	1.9	85	50			y		y		17

3.4 Other considerations on system ranking

Apart from criteria applied to rank the systems included in this inventory, there may be particular considerations which would either preclude or favour the use of systems that have particular properties. In the following, we evaluate whether and how the results of the ranking change when particular filters are applied.

Given a large existing fleet, it is probably preferable to retrofit vehicles in the fleet with BSMSs, rather than to replace vehicles with new vehicles that include BSMSs as OEM option. We evaluate how this consideration changes the outcome of the ranking by filtering out systems that are not available as retrofit option. Application of this filter results in removal of 16/60 systems, leaving 44 (73.3%). Application of this filter did not affect any of the top-ranking systems, regardless of the category of the system viewing direction.

Another consideration is that warning systems still rely on the driver to take the proper action in response to a warning in order to prevent crashes. Consequently, one may prefer systems that intervene, for instance by braking, when a driver does not respond to a warning. In the obtained sample of systems, only two systems had intervening functionality. These were the MAN Lane Change Collision Avoidance Assist (*Appendix E.19.4*) and the ZF TailGuard system (*Appendix E.35.2*). These systems ranked 52/60 and 32/60, respectively, and therefore do not affect the recommendations. Nonetheless, it should be noted that these systems are only available as OEM solutions, and not as retrofit solutions. A likely reason for this is that false alarms have particularly undesirable consequences for intervening systems, and manufacturers cannot practically ensure that retrofit solutions are placed and calibrated optimally; meaning that intervening retrofit solutions may not have an optimal classification ability, and thereby impose unacceptable risks.

Finally, when a complete solution is desired, that is, a system monitoring the entire surround of a vehicle and operational under all circumstances, it may be preferable to use system(s) from one particular supplier. Consequently, we may consider systems that offer a complete solution, or modular systems by a given supplier, which can be combined into a complete solution.

3.5 Main findings

When we consider the rankings (*Section 3.3*) taking the above considerations (*Section 3.4*) into account, we can make the following recommendations:

- Overall, the best ranked system is the Autel Blind Spot Assist (*Appendix E.1.1*). However, this system is suitable only to monitor objects in the vehicle’s lateral blind spots.
- When considering the single best system that is suitable for monitoring all directions, the eXia Active Sideguard system (*Appendix E.14.1*) appears to finish in the top-three for all viewing directions. However, this system is rather exotic, in that the sensor technology (monitoring the electric field) is not used by any other manufacturer. We do not know how well this system works in practice (scientific validity).
- The next-best multi-directional solution using more common radar technology is the Sensata PreView Sentry (*Appendix E.27.2*). Another advantage for choosing this particular manufacturer could be the availability of variations of this system (see *Appendix E.27*)
- The best ranking multi-directional camera system is the oToGuard system by oToBrite. This is a single integrated solution to monitor all directions, which also features an in-cabin camera to monitor the driver, and which is compliant with multiple UNECE regulations (*Appendix E.22.2*).

4 Overview of alternative measures

This chapter features a separate overview of measures to reduce blind spot crashes, which do not involve systems for detecting other road users around HGVs and informing the driver about or intervening in the traffic situation.

We can classify countermeasures that do not involve blind spot detection systems for blind spot crashes with heavy goods vehicles in the following categories: other measures to support the driver of the HGV, measures to separate HGVs and other road users in time or space and measures to support other road users. These will be described in the paragraphs below. We will shortly introduce the measure, write down the organisation that is responsible for the measure and the degree to which the measure is implemented.

The information described in this chapter is derived from existing SWOV reports and fact sheets (Mesken, Schoon, & van Duijvenvoorde, 2012; Schoon, 2012; Schoon, Doumen, & de Bruin, 2008; SWOV, 2020a, 2020b). The main topic of these reports is the blind spot problem involving right turning HGVs and cyclists. This particular blind spot problem is of great concern in the Netherlands because of the high number of cyclists on Dutch roads and thus frequent interactions between cyclists and HGVs. It is possible that the latest insights on the topic are not discussed in this chapter. For example, we do not know if there is scientific proof of the effectiveness of these measures in reducing the number of blind spot crashes. At the end of the chapter, we will discuss the transferability of the knowledge derived from the reports and fact sheets to other blind spots around the HGVs.

4.1 Measures to support the driver

The first group of measures are the measures that can support the driver of the HGV. This group consists of measures to inform the driver of the blind spot problem and ways to deal with it effectively (education and safety culture) and measures that involve adjustments of the vehicle or road lay-out to support the driver during blind spot-sensitive movements (blind spot mirrors on the HGV or the road and optimising cabin design to maximise the view of the surroundings).

4.1.1 Life-long education of drivers

The drivers of HGVs should be reminded regularly of the dangers of the blind spots surrounding their vehicles and the behavioural measures they should take to minimize the risk of not seeing other road users. They can follow refresher courses that pay attention to blind spot detection. For example, when turning right they should perform checks of blind spot mirror and/or systems while waiting at an intersection and perform a last inspection of the blind spot just before turning to the right. In The Netherlands, refresher courses are compulsory for truck drivers to retain their drivers' licence. However, they have some freedom in the choice of courses they take.

4.1.2 Safety culture at Transport companies

The safety culture of a company is constituted by the joined safety standards and values of all co-workers within the company. Company policies should promote a healthy safety culture among co-workers. For a transport company a part of the safety culture should be about safe driving, and should therefore address the problem of blind spots around HGVs. Encouraging refresher courses on the topic may be part of a company's strategy. Other important issues within safety culture should be to maintain a low workload while driving (examples are implementing reasonable delivery schedules to reduce stress levels of drivers and complying with the legal driving time and rest requirements), to have a dashboard free of items that block the view through the windshield, to use safe routes and to use dedicated navigation systems.

4.1.3 Blind spot mirrors on the vehicle

Blind spot mirrors or detection systems are obligatory on HGVs within the EU. EU legislation describes a mandatory field of vision around trucks, which can be obtained by mirrors or detection systems. We do not have information about legislation on field of vision around the truck in countries outside the EU. Vehicle manufacturers should oblige to the legislations and transport companies and the drivers themselves should monitor the presence and use of the available systems.

4.1.4 Optimising direct vision of drivers

Lowering the position of the entire cabin of the truck, including the position of the driver, will reduce the size of the blind spot in front and to both sides of the cabin of the truck. This lowering of the cabin will enable the positioning of a glass door and thereby enlarging the direct vision to the right side of the driver.

4.1.5 Blind spot mirrors on the road

In some countries, blind spot mirrors are placed on traffic light poles to broaden the view drivers have at that location. These mirrors are not discussed in our reports. However, they can be useful at the entrance of the designated area of a (transport) company, where HGVs often make turns to enter the parking lot of the company.

Improving the driver’s view through direct vision, or blind spot mirrors on the vehicle or the road, will in theory give the driver the opportunity to see other road users. However, the driver should look in the right mirror or direction at the right moment. Thus, the use drivers make of these measures is a factor that determines the road safety effect of the measures.

4.2 Measures to separate HGVs and other road users in time and space

Minimizing interactions between HGVs and other road users is a good strategy to avoid conflicts of HGVs with other road users. Complete avoidance of interactions is not possible, but it is possible to avoid the most dangerous interactions: the interactions of HGVs with vulnerable road users (pedestrians and cyclists), the most dangerous roads and dangerous time windows. We will discuss some measures that are or can be implemented in traffic systems. As mentioned at the start of this chapter, the measures are directed at reducing traditional Dutch blind spot crashes. We will start with the most effective, long-term strategic measures and end with more short-term practical measures.

4.2.1 System changes in freight traffic

A long-term measure that eliminates possible conflicts between HGVs and vulnerable road users like cyclists constitutes a change of the system of freight traffic. The ideal situation is that HGVs will be restricted to the main road network that gives access to distribution centres at the border of urban areas. Departing from these distribution centres, only light freight traffic will be allowed to use the secondary road network, the roads where more interaction between vehicles takes place and thus conflicts with vulnerable road users do arise. These light freight vehicles have the advantage that they often have a lower position of the cabin and thus provide more direct vision of the area around the cabin.

Such a freight traffic system needs structural changes in freight traffic logistics. The government should encourage companies to implement them. However, companies can choose to enter urban areas with light freight vehicles as often as possible in absence of such encouragement.

4.2.2 Time windows freight traffic

If it is not possible to separate HGVs and vulnerable road users in space, another option is to separate them in time. City councils and/or the transport companies can agree on fixed time windows for HGVs to enter urban areas. Best is to allow HVGs to enter urban areas when there is less traffic, for example not at rush hours, and when there are only few of the most vulnerable road users in the street, for example not around start and end times of schools in the neighbourhood.

4.2.3 Safe routes for freight traffic

Another option is to guide HGVs through urban areas via roads where they can drive relatively safely, without too much interaction with other road users. For instance, they could drive on through-roads (in Dutch: ‘stroomwegen’) and distributor roads (in Dutch: ‘gebiedsontsluitingswegen’) for as long as possible. If HGVs only drive on access road (In Dutch: ‘erftoegangswegen’) just before reaching their destination, they will have the least interaction with vulnerable road users. Manufacturers of HGVs and navigation systems should provide dedicated navigation tools for HGVs that show the safest routes. A specialised navigation system can, for instance, guide HGVs to roads with bicycle tracks instead of bicycle lanes and avoid streets where schools are located. Transport companies should encourage their drivers to drive along the safest routes and provide the necessary information, for instance by stimulating the use of dedicated navigation systems.

4.2.4 Intersection measures

Separating HGVs and vulnerable road users can also be accomplished on a smaller scale: at intersections. A possibility to separate HGVs from cyclists at intersections is to create a bike box (In Dutch an ‘Opgeblazen Fiets OpstelStrook’ or OFOS), where cyclists can position themselves a few metres in front of the motorised vehicles and in this case the HGVs. An alternative is to create distance between HGVs and cyclists by bending the cycle lane to the right before an intersection. Both infrastructural measures separate HGVs and vulnerable road users a few extra metres, which allows the driver to see them directly. Another possibility is to separate cyclists and HGVs in time at signalised intersections by introducing a separate green light phase for cyclists.

4.3 Measures to support other road users

4.3.1 Signs on trucks

A sticker on the different sides of the truck to attend other road users to blind spots around the vehicle can raise awareness about the reduced vision of the driver and thus the danger of positioning oneself close to the vehicle. But we do not know if the effectiveness of these stickers in preventing crashes with HGVs has been investigated.

4.3.2 Education of vulnerable road users

Education on how to behave when near an HGV is provided at most primary schools in The Netherlands. In a 2008 SWOV report we proposed introducing a code of conduct for cyclists: ‘When standing next to an HGV at a traffic light, stay in front of the vehicle. However, when you approach the HGV from behind, stay behind the vehicle and cross the road after the vehicle has turned to the right.' This code of conduct is not followed everywhere in the Netherlands. It raises the discussion of responsibility for the situation: is the driver responsible or the vulnerable road user?

4.4 Transferability of knowledge to other blind spots

The above knowledge is derived from research about the blind spot directly to the right and in front of the cabin of the HGV, in interaction with cyclists and to a lesser extent pedestrians. In this paragraph, we will mention our thoughts about transferability of this knowledge to the other blind spots around the vehicle in interaction with all possible road users.

Some *measures to support the driver* during blind spot situations in traffic can help in all blind spot scenarios: educating drivers and improving the safety culture of companies may be applied to all blind spots surrounding HGVs. For this to work, educational programs and company safety cultures should take all blind spot situations into account. Strategically placed blind spot mirrors on the road can help reduce the blind spot behind the vehicle at locations where HGVs have to manoeuvre at dedicated areas for collecting or delivering goods, but not for blind spots in case of lane changes while driving on roads with multiple lanes. Traditional blind spot mirrors around the cabin of the driver can be used to detect pedestrians around the cabin of the vehicle, but do not reduce the blind spot behind the driver or to the left of the cabin. For all large vehicles, it is important to optimise direct vision in all directions. Although it is often not possible to enlarge direct vision right through the vehicle to the rear, it is food for thought to investigate the necessity for the vehicle at hand to have a blocked view backwards. For instance, is it possible to design a vehicle in such a way that the large parts of the vehicle are lower when the vehicle is driving? When working vehicles are manufactured or bought, it is wise to consider optimising direct vision around the vehicle as much as possible, taking into account the purpose of the vehicle.

The effectiveness of the *measures that separate HGVs and other road users* in time or space vary as well. If only light freight vehicles are allowed in urban areas, interaction of HGVs with road users is restricted to the main roads and private properties of companies. In the Netherlands, main roads (motorways) are relatively safe roads (SWOV, 2022). We assume that this is also the case in other countries. Thus, only driving with light vehicles, with very small blind spots, in urban areas is effective in reducing some types of blind spot crashes. However, also light freight vehicles have blind spots at the rear of the vehicle while manoeuvring, and to a lesser extent to the sides while changing lanes. So, part of the blind spot problem will still exist in the suggested freight traffic system. Working with relative safe time windows to drive with HVGs will reduce all blind spot problems to a degree. However, the safer routes and intersection measures are quite restricted to interactions with vulnerable road users and therefore do not affect problematic interactions with motorised vehicles. The safer routes through urban areas more often have multiple lanes for motorised traffic, and thereby enlarge the blind spot problem while changing lanes. If the destination of the HGV is not changed, the manoeuvring (with driving backwards) around the destination still has to take place, so it will not reduce blind spot situations at the rear of the vehicle. The use of special time windows and safe routes can be applied to the private premises of companies. For example, it is possible to ban driving with HGVs at premises where and when co-workers walk during lunchtime or walk towards or from the parking lot (at opening and closing times of the office).

Measures to inform other road users can of course in theory be transferred to more blind spot scenarios than the traditional Dutch blind spot problem. The use of stickers at the rear of the truck, in combination with the sound that is usually accompanied by a reversing HGV, could raise awareness of the dangerous situation to anyone standing behind the vehicle. However, stickers warning of blind spot hazards related to lane-changes placed on the left side of the vehicle may not be an effective means to warn motorised road users to the left of the vehicle, as such stickers are unlikely to be seen. Usually, the other road user, who is busy overtaking the HGV, is looking at other aspects of the traffic environment and driving at a speed too high to see and process the information on the sticker. Education about the blind spot for all scenarios and road users would be so extensive or superficial, that we do not really see lots of possibilities for road safety improvement here. Of course, it is possible to direct educational messages to specified groups, for example the blind spot education for primary school children (a Dutch example) or information sessions for the co-workers of transport companies that do not drive themselves, or for the company's neighbours.

5 Discussion

To create the present inventory, a comprehensive search was performed using the Google search engine. Search terms were obtained from official regulations on blind spot monitoring systems and augmented with terms provided by experts. Search results were scanned for commercially available systems and for any mentions of systems in news articles. These efforts yielded an initial number of 83 systems that were potentially within the scope of this inventory. Further evaluation of these systems resulted in a list of 65 systems by 35 manufacturers. On the basis of documentation and/or communication with manufacturers, sufficient information for comparative analyses was ultimately obtained for 60 systems, by 33 manufacturers. In the following, we present general considerations on the findings, provide practical recommendations, and we discuss limitations of the study.

5.1 General considerations

BSMSs may improve a driver's situational awareness by alerting them to hazards that may be invisible to them or could otherwise escape their attention. However, as emphasized by numerous manufacturers in user manuals, these systems should be considered aides only, and cannot take over ultimate responsibility from the driver. Consequently, it is worthwhile to point out the importance of non-vehicle measures (*Chapter 4*): life-long education of drivers as to the use of all available safety systems and a company's safety culture which should stress the importance of safety from a company perspective. In addition, measures can be taken to minimise the extent to which vehicle and VRU operating environments (i.e., road, marshalling yards, etc.) overlap; both spatially as well as temporally. Although there is no scientific evidence unambiguously showing benefits of campaigns, it may be posited that raising awareness in VRUs of the dangers of vehicle blind spots might have beneficial effects as well.

Although studies on the effects of BSMSs in HGVs and buses on crash risk are lacking, studies on passenger cars (e.g., Cicchino, 2017; Cicchino, 2018, Cicchino, 2019) suggest that BSMSs do, at the very least, have the potential to improve safety, and as such, are a valuable addition to the range of driver assistance systems. BSMSs use either of, or any combination of, three general classes of sensors. These are *ultrasonic sensors, radar sensors,* and *cameras*. Ultrasonic sensors emit vibrations at frequencies beyond the range of human hearing, and detect reflections of the emitted signals. Radar sensors work on a similar principle, but instead emit microwaves (electromagnetic radiation with wavelengths of 1m-1mm). Cameras detect light reflected off of objects (i.e., electromagnetic radiation in the range visible to the human eye - wavelengths 400-750nm); infrared cameras are sensitive to the range of wavelengths just beyond human sensitivity 750nm-1mm. In general, the sensor specifications provided by manufacturers indicate that ultrasonic sensors are effective for a relatively short range, up to approximately 5m; radar sensors can be effective for a longer range, up to some 250m. For either type of sensor, the output is essentially a direct indication of object presence. With additional processing, object motion can be inferred, allowing classification of objects as particular types of road users. Camera sensors provide an image of the surroundings, and require processing by means of computer vision algorithms to yield classifications of object presence, and further processing to infer the type and motion of the detected object. Within each class of sensors, the specifications of the sensors were typically sufficient to make a comparison, although the differences between sensors of a given class turned out to be relatively small. This inventory features one system with an alternative sensing technology; the eXia Active Sideguard (*Appendix E.14.1*). This system detects objects based on near-field interaction with a low-frequency electric field. Unlike radar, camera and ultrasonic sensors, the electrostatic sensing principle is not dependent on a line of sight. Thus, even when the sensor's line of sight is blocked, the Active Sideguard system can render a 3D image of its surroundings.

The inventory included 15/60 ultrasonic systems; 31/60 radar systems; 11/60 camera systems and 1/60 system that monitors the electric field. For two systems, the sensor class could not be determined. Unit costs tended to be the lowest for ultrasonic systems, followed by radar systems, and finally camera systems and the electric field system. The large majority of systems are available only as retrofit solutions, and provide warnings but do not intervene with the driving task, there is no emergency braking for instance. In fact, our inventory does not include any retrofit-intervening systems. The reason for this is probably that, when 3rd parties install their systems, manufacturers cannot ensure a sufficiently high classification performance to prevent false alarms, which can have particularly undesirable consequences for intervening systems (e.g., unnecessary emergency stops).

In general, ultrasonic sensors appear to provide the most practical solution for short-range detection/low-speed manoeuvring (i.e., loading zones, marshalling yards, off-motorway vehicles), while radar sensors appear to be most practical for long-range detection/high-speed manoeuvring (e.g., detection of other road users in blind spots during motorway driving). Camera images can be shown to a driver, and improve situational awareness by showing them *what* is present in a blind spot, rather than just alerting drivers to the presence of *something* in the blind spot. This feature will probably be appreciated by drivers, but may not be strictly necessary to prevent crashes.

5.2 Top ranking systems

We consider systems by monitoring direction in order to facilitate an overview of systems and manufacturers which can cater to multiple use cases. The top 3 ranking systems for each monitoring direction (Forward: *Table 5.1*, Side: *Table 5.2*, Rear: *Table 5.3*) were:

Forward

Table 5.1. Top-three systems intended for monitoring the front of the vehicle.

Position	Manufacturer	System name	Class	Overall rank
1	eXia	Active Sideguard	electric field	3
2	Sensata	PreView Sentry	radar	7
3	oToBrite	oToGuard	camera	8

Side

Table 5.2. Top-three systems intended for monitoring the side of the vehicle.

Position	Manufacturer	System name	Class	Overall rank
1	Autel	Blind Spot Assist	radar	1
2	oToBrite	oToBrite BSIS	camera	2
3	eXia	Active Sideguard	electric field	3

Rear

Table 5.3. Top-three systems intended for monitoring the rear of the vehicle.

Position	Manufacturer	System name	Class	Overall rank
1	eXia	Active Sideguard	electric field	3
2	CandidTech	Bus all-around blind spot detection system	radar	4
3	Rostra Accessories	Blind spot detection system 3.0	radar	6

5.3 Recommendations

The ultimate purpose of BSMSs is to alert drivers to the presence of objects in blind spots; regardless of whether an object is stationary and inanimate or whether it is a VRU, drivers must always strive to prevent crashes. Therefore, classification of the nature of the detected object may be considered of secondary importance relative to detection performance. Surprisingly, detection performance does not appear to be evaluated in empirical tests for the majority of products, or at least, data and test reports were not shared. This means that although the qualities of sensors could, to some extent, be evaluated, there is no reliable indication of real-world detection performance, in terms of sensitivity and specificity, by the system as a whole for most of the systems included in the present report. Out of the 60 systems included in the inventory, some indication of sensitivity was obtained for only 6 systems (10%); and some indication of specificity for only 3 (5%). The available data typically *suggest* a very good performance (>95%). However, a report of an empirical study performed to evaluate a system was available for only one system (Frampton & Millington, 2022). Interestingly, while this study found that the system under study had near perfect specificity, it only had a sensitivity of about 50%, meaning that in half of the cases where there was something in the blind spot, the system failed to detect it. This puts into question whether the real-world detection performance of other systems is acceptable.

One recommendation therefore is to acquire sample systems for those systems that, on paper, best match the requirements, and to actually perform empirical tests to determine real-world detection performance. A rough sketch of an experimental paradigm would be to equip a small sample of vehicles representative of the three business cases presented to the manufacturers (e.g., one box truck, one tractor/semi-trailer combination, and a crane) with each of the systems, and subsequently, for each of the vehicle/system combinations, to perform a series of 'experimental trials' in which a mock-VRU is either present or absent, and to note the number of true and false positives and negatives for each system. Classification performance for each system can subsequently be quantified using metrics such as the receiver operating characteristic. In addition, usability tests may be performed to assess, e.g., the learnability of the system, ease of use, and driver workload (cf. recommendations in Hoedemaeker et al., 2010).

Apart from system performance, another dimension relevant to implementation is the cost of systems. Cost of systems appears to be related primarily to the amount of signal processing performed. Systems that use ultrasonic sensors tend to be the least expensive, followed by radar sensors, while camera systems are the most expensive. Given that availability of camera feeds may not be strictly required to alert drivers to the presence of VRUs, a practical recommendation for equipping a large fleet with BSMSs could therefore be to equip vehicles that are only used off-motorway with ultrasonic sensors, and other vehicles with radar systems.

Overall, the best ranked system is the Autel Blind Spot Assist (*Appendix E.1.1*). However, this system is suitable only to monitor objects in the vehicle's lateral blind spots. When we consider the single best system suitable to monitor all directions, we find that the eXia Active Sideguard system (*Appendix E.14.1*) is present in the top-three systems, regardless of viewing direction.

However, this system uses a sensor technology that is not used by any other manufacturer, and given that there is no evaluation of the system's scientific validity, we prefer to exercise caution in recommending this system. The next-best solution suitable to monitor all directions, which uses the most common radar technology is the Sensata PreView Sentry (*Appendix E.27.2*; position 2 for forward monitoring; position 6 for side, and 5 for rearward monitoring). An additional advantage for choosing this particular manufacturer could be the availability of variations of this system (see *Appendix E.27*). The best ranking multi-directional camera system is the oToGuard system by oToBrite (apart from the top-3 positions for forward and side monitoring; position 6 for rearward monitoring). This is a single integrated solution to monitor all directions, which also features an in-cabin camera to monitor the driver, and which is compliant with multiple UNECE regulations (*Appendix E.22.2*).

In Europe, compliance with BSMS-related UNECE regulations (e.g., R151, R158, and/or R159, depending on the monitoring direction) has been a prerequisite for type approval of new trucks and buses since 6 July 2022 (EU Regulation 2144/2019). Compliance with these regulations is not mandatory for retrofit systems, but nonetheless it could be viewed as a minimum requirement for all BSMSs (and for this reason it was used in the ranking). Not all BSMSs in our inventory were coded as compliant. However, this does not necessarily mean that these BSMSs were non-compliant. Potentially, systems were assessed on compliance and did meet the requirements, yet no (explicit) information on compliance was made available. Alternatively, systems were not assessed on compliance (possibly due to ambiguous classification, see *Section 5.4*), but would have been compliant when subjected to an assessment. For future evaluation of systems, and provided that supplementary information is provided by the corresponding manufacturers, *Appendix F* indicates some of the technical requirements that should be met to comply with the above UNECE regulations.

5.4 Study limitations

A number of potential limitations of the Google search engine were encountered while performing the search. First, queries are limited to 32 words. Therefore, it was not possible to combine all queries into a single command, and multiple search queries were performed (see *Appendix B*). While reviewing the results of the searches, two peculiarities of Google's search engine were observed. First, repeated evaluation of a given search query did not consistently yield the same number of results; second, explicitly excluding a specific search term from a query, for instance *-site:"www.amazon.com"* occasionally resulted in an *increase* in the number of search results, whereas logically the number of results should decrease. These observations, along with the fact that the ranking and inclusion of results may be biased by sponsoring, imply that we cannot be certain that all potentially eligible systems were identified.
Although data could ultimately be retrieved for 60 systems by 33 manufacturers, the proportion of manufacturers that responded to inquiries was disappointing. Inquiries about systems were sent to a total of 42 manufacturers for 83 systems (including some manufacturers whose systems were, upon further consideration, deemed outside the scope of the inventory). Initial contact requests were sent primarily via e-mail, or via website contact forms when no e-mail address was found on the company website (see *Appendix D* for cover letter). When only a phone number was available, a call was placed to retrieve contact information for product owners or sales departments. Reminders were sent to companies that did not respond when the initially given deadline had passed (i.e., two weeks from the initial inquiry), offering a one-week extension. Out of all inquiries, responses/leads were obtained for only 17 systems, and only nine manufacturers provided information for all systems that were included the inquiry. It often proved to be difficult or even impossible to get through to the right person. One major company that advertises various BSMSs solutions (i.e., Bosch) has separate contact forms on websites for different systems. For one of those four solutions, contact was established with a sales representative after initial inquiry. For the others, at least two subsequent reminders were sent. We received

standard notifications of receipt, stating that: “With small quantities, these expenses are in an uneconomical ratio to the actual product costs. That is why, in the interests of our customers, we can only make an offer for series production with large quantities.” When we emphasized the business cases in responses to this message, we were instructed to once again fill out the contact form. Ultimately, we were unable to get through to the right person. Although the above is anecdotal, we feel that responsiveness and willingness to provide information may be indicative of the availability of companies for cooperation and troubleshooting, which are commendable qualities.

Another possible limitation of the study is the choice of information categories. System classifications were performed on the basis of properties such as the type of vehicle (rigid, articulated, off-motorway), UNECE vehicle classifications (M2, M3, N2, N3), and the type of functionality or conformity with particular UNECE regulations (e.g., BSIS, MOIS, REIS). Whereas regulations appear to apply quite strictly to certain classes of blind spots and vehicles, it was found that manufacturers classify their systems on different properties in practice. Moreover, overlap is possible between different properties, so that it proved awkward to characterise systems in a small number of mutually exclusive categories. For instance, vehicles of M/N UNECE classifications can be both rigid or articulated. This variability in methods to classify systems complicates the definition of groups by which systems can be compared, that is, it is not always apparent whether a system should be included in one group or another.

Apart from variables by which to group systems, there are also limitations on chosen performance criteria. Here, the most important limitation is the availability of real-world evaluation data on Scientific Validity (as discussed in the ‘General considerations’ section). However, the chosen categories for sensor evaluations were also not all perfectly fitting. By way of illustration, at the outset of the project, it was thought that the area monitored by a sensor could be defined as a cone with an oval or circular base, of which the apex coincides with the centre of the sensor surface. Based on this assumption, a concise description of the sensor could be given by noting its horizontal and vertical viewing angle (i.e., the Field-of-View) and the range. Measures of sensor FoV accuracy and precision could then be given in typical values for constant and variable errors of these metrics, and sensor resolution could be quantified as the fraction of the FoV an object must cover to result in correct detection for a given minimum number of independent cases. However, it turned out that various radar sensors consist of two antennas; one for the near-range, and one for the far range. In such cases, the area monitored by the sensors would actually be better described by a mixture of two cones. This is just to illustrate that not all categories were as fitting or unambiguous as they were thought to be when they were first defined.

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Appendix A Definitions & Scope

This appendix reports regulations related to BSMSs, the blind spots around vehicles and the vehicles that have large blind spots.

A.1 Regulations related to Blind Spot Monitoring Systems

Various UN Regulations with the objective of establishing uniform standards for vehicles and their components relating to safety, environment, energy and anti-theft requirements are available as addenda to the 1958 Agreement titled: "*Agreement concerning the adoption of uniform technical prescriptions for wheeled vehicles, equipment and parts which can be fitted and/or be used on wheeled vehicles and the conditions for reciprocal recognition of approvals granted on the basis of these prescriptions.".* This Agreement in general aims at promoting the harmonisation of Regulations and mutual recognition of approvals amongst Contracting Parties to the Agreement.

In principle, regulations that are in force legally bind Contracting Parties which signed the same Regulation.[3] This means that (1) Contracting Parties which signed a Regulation may issue type approvals according to that Regulation and (2) that they shall recognise the type approvals issued by all other Contracting Parties which signed the Regulation too. As per these regulations, manufacturers are required to provide the Technical Service and Type Approval Authority with documentation that demonstrates that the BSMS performs as specified. Of relevance to this inventory, is that this implies that documentation must exist for any system that has official approval.

In addition to UNECE regulations, Article 9 of EU regulation EU2019/2144 rev. 05/09/2022, states that vehicles in categories M and N (buses and trucks) must be equipped with "advanced systems that are capable of detecting pedestrians and cyclists located in close proximity to the front or nearside of the vehicle and of providing a warning or avoiding collision with such vulnerable road users," and that they should be designed "to enhance the direct visibility of vulnerable road users from the driver seat, by reducing to the greatest possible extent the blind spots in front of and to the side of the driver." This indicates that some form of computerised warning system will be officially required for new vehicles in the EU.
At the time of writing, there are 165 addenda to the general agreement. More recent additions, considering more recent technologies, rank higher in addendum number. In order to collect and formalise search terms that delineate the scope of this inventory, we considered the following addenda:

- Regulation No. 46 - Uniform provisions concerning the approval of devices for indirect vision and of motor vehicles with regard to the installation of these devices;
- Regulation No. 151 - Uniform provisions concerning the approval of motor vehicles with regard to the Blind Spot Information System for the Detection of Bicycles;

3. UN/ECE regulations are not legally binding by themselves. In Europe, the appendices of regulation 2019/2144 state which set of UN/ECE regulations are to be complied with by manufacturers for type approval.

- Regulation No. 158 - Uniform provisions concerning the approval of devices for reversing motion and motor vehicles with regard to the driver's awareness of vulnerable road users behind vehicles;
- Regulation No. 159 - Uniform provisions concerning the approval of motor vehicles with regard to the Moving Off Information System for the Detection of Pedestrians and Cyclists.

Regulation No. 46 was included after noting that it was referred to in later regulations, which specify requirements for BSMSs in terms of a classification of blind spots defined there.

A.2 Classification of blind spots

Specifications of different blind spot classes given in Regulation No. 46 were found to guide definition of later regulations. Therefore, it is convenient to consider these classifications prior to discussing regulations that refer to these classes. Regulation No. 46 lists requirements for devices that can provide indirect vision (e.g., mirrors). The requirements are defined in terms of an offered Field-of-View (FoV), referring to particular areas of the vehicle's visual surroundings, relative to the Driver's Ocular Points (DOP; i.e., the location of the driver's eyes relative to the vehicle: two points 65mm apart, 635mm above a certain point on the driver seat). A description of the classifications provided there is provided in *Table A.1*; visualisations of the blind zones are shown in *Table A*.2.

Table A.4. Viewing area classifications as in UNECE R46. DOP means "Driver's Ocular Points", i.e., the location of the driver's eyes in the vehicle.

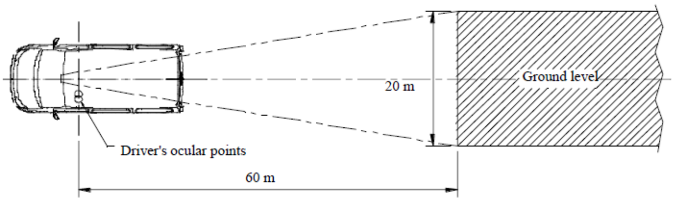
Class ID	Description	Specification	Field-of-View
I	Rear-view device		20m wide @ 60m behind DOP; extending to horizon
II	Main rear-view device	driver side	1m wide @ 4m, and 5m wide @ 30m behind DOP; extending to horizon
		passenger side	*as above*
III	Main rear-view device	driver side	1m wide @ 4m, and 4m wide @ 20m behind DOP; extending to horizon
		passenger side	*as above*
IV	Wide-angle view device	driver side	4.5m wide area @ 1.5m, and 15m wide @ 10m behind DOP; extending at least to 25m
		passenger side	*as above*
V	Close-proximity view device	passenger side; existing	2m wide area extending 1m to the front, and 1.75m behind DOP
		passenger side; larger	4.5m wide area extending 3m to the front rounded off with 2m radius, and 1.75m behind DOP
VI	Front-view device		2m area directly in front of vehicle, extending to 2m beyond passenger side of vehicle, rounded off with 2m radius
VII	Main rear-view mirrors cat. L	driver side	2.5m wide area @ 10m behind DOP, extending to horizon
		passenger side	4m wide @ 20m behind DOP, extending until horizon

Class I can be interpreted as a conventional rear-view mirror; classes II, III and VII can be interpreted as conventional side-view mirrors, differing in the offered FoV; class IV refers to devices that offer a wide-angle view of the sides of the vehicle; class V offers the driver a view of the immediate surround on the passenger's side; and class VI offers a view of the area directly in front of the vehicle, which is otherwise occluded due to the height of the driver and windscreen relative to the ground.

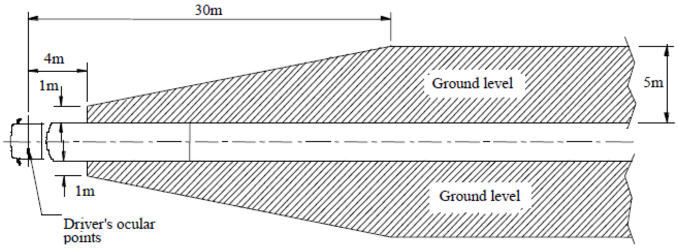
Table A.5. Visualisations of blind spots as used in UNECE regulations.

Blind spot class

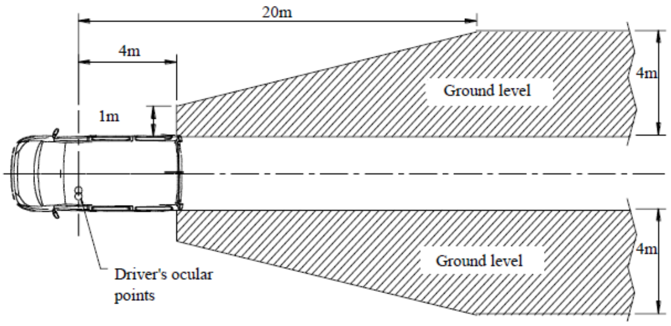
I



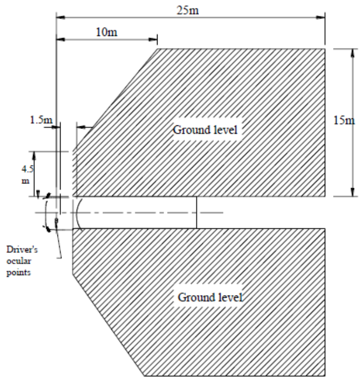
II



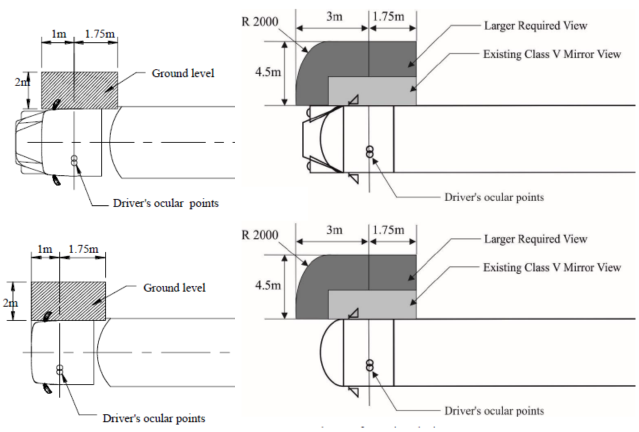
III



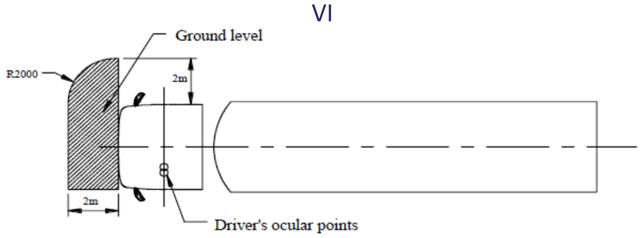
IV



V



VI



A.3 Vehicle classifications

Vehicle classifications as used in this document are defined in accordance with Directive 2007/46/EC of the European Parliament and of the Council of 5 September 2007 “establishing a framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles.” As per prior agreement, vehicles within the scope of this study are Heavy Goods Vehicles (HGV, also known as Large Goods Vehicle, LGV) and buses[4]. The corresponding official classifications are vehicles of categories **M2** and **M3**, i.e., buses seating more than eight people plus driver, of < c.q. > 5000kg, respectively, and categories **N2** and **N3** (i.e., commercial vehicles with masses > 3500kg and >12000kg, respectively); and trailers (categories **O1**, **O2**, and **O3**, of <3500kg, >3500kg, <10000kg, respectively).

For the categories that are both covered in the regulation and relevant to the scope of the present review (i.e., M2, M3, N2, N3) a simplified overview of the required classes of devices is given in *Table A*.3. Exemptions and additions to this overview are described in Directive 2007/46/EC.

Table A.6. Viewing device classes required per vehicle category.

Vehicle category	Class					
	I (rear-view)	II (main rear-view)	III (main rear-view)	IV (wide-angle)	V (close-proximity)	VI (front-view)
M2	optional	compulsory	not permitted	optional	optional	optional
M3	optional	compulsory	not permitted	optional	optional	optional
N2 ≤ 7.5t	optional	compulsory	not permitted	compulsory	compulsory	optional
N2 > 7.5t	optional	compulsory	not permitted	compulsory	compulsory	compulsory
N3	optional	compulsory	not permitted	compulsory	compulsory	compulsory

4. In addition, we consider other large vehicles, such as construction vehicles, and mining vehicles. To the best of our knowledge, these are not considered in official regulations.

Appendix B Search queries

Google search limits queries to 32 words. Therefore, multiple search queries have been constructed. *Table B.4* displays a list of the search queries performed to obtain a total of 71 candidate blind spot detection systems. During the search process, two peculiarities of Google's search engine were observed. First, repeated use of the search queries listed in *Table B.4* may not yield the same number of hits. Second, excluding a specific search term from the results (e.g., -site:"www.amazon.com" in search query #3) occasionally resulted in an *increased* number of hits (e.g., 111 hits in search query #3 versus 98 hits in search query #2), where a *decrease* was expected.

Table B.7. Search queries performed in order of appearance (ID) to identify candidate blind spot detection systems. 'Hits' corresponds with the number of results using Google Search. 'Relevant' corresponds with the number of newly identified candidate systems in addition to the previous search query.

ID	Description	Query	Hits	Relevant
1	First exploration	("blind spot" OR "blind-spot") AND ("monitor" OR "Information System") AND "heavy goods vehicle"	20800	5
2	Warning systems	intitle:"blind spot warning system" OR intitle:"blind-spot warning system" OR intitle:"blind zone warning system" AND ("truck" OR "heavy goods vehicle" OR "bus")	98	1
3	Warning systems without amazon and aliexpress	intitle:"blind spot warning system" OR intitle:"blind-spot warning system" OR intitle:"blind zone warning system" AND ("truck" OR "heavy goods vehicle" OR "bus") -site:"www.amazon.com" -site:"www.aliexpress.com"	111	6
4	Warning systems, coach (instead of bus)	intitle:"blind spot warning system" OR intitle:"blind-spot warning system" OR intitle:"blind zone warning system" AND "coach"	5	0
5	Monitoring systems	intitle:"blind spot monitoring system" OR intitle:"blind-spot monitoring system" OR intitle:"blind zone monitoring system" AND ("truck" OR "heavy goods vehicle" OR "bus") -site:"www.amazon.com" -site:"www.aliexpress.com"	879	3
6	Monitoring systems, coach (instead of bus)	intitle:"blind spot monitoring system" OR intitle:"blind-spot monitoring system" OR intitle:"blind zone monitoring system" AND "coach"	2	0
7	Detection systems	intitle:"blind spot detection system" OR intitle:"blind-spot detection system" OR intitle:"blind zone detection system" AND ("truck" OR "heavy goods vehicle" OR "bus") -site:"www.amazon.com" -site:"www.aliexpress.com" -site:"www.alibaba.com"	2720	11
8	Detection systems, coach (instead of bus)	intitle:"blind spot detection system" OR intitle:"blind-spot detection system" OR intitle:"blind zone detection system" AND "coach"	104	1
9	Allied Market Research report	N.A.	N.A.	12
10	Assistance systems	intitle:"blind spot assist" OR intitle:"blind-spot assist" OR intitle:"blind zone assist" AND ("truck" OR "heavy goods vehicle" OR "bus" OR "coach") -site:"www.amazon.com" -site:"www.aliexpress.com" -site:"www.alibaba.com"	2900	1

ID	Description	Query	Hits	Relevant
11	Assistance systems, without Mercedes-Benz	intitle:"blind spot assist" OR intitle:"blind-spot assist" OR intitle:"blind zone assist" AND ("truck" OR "heavy goods vehicle" OR "bus" OR "coach") -site:"www.amazon.com" -site:"www.aliexpress.com" -site:"www.alibaba.com" -mercedes	895	3
12	Information systems	intitle:"blind spot information system" OR intitle:"blind-spot information system" OR intitle:"blind zone information system" AND ("truck" OR "heavy goods vehicle" OR "bus" OR "coach") -site:"www.amazon.com" -site:"www.aliexpress.com" -site:"www.alibaba.com"	478	3
13	Intervention systems	intitle:"blind spot intervention" OR intitle:"blind-spot intervention" OR intitle:"blind zone intervention" AND ("truck" OR "heavy goods vehicle" OR "bus" OR "coach") -site:"www.amazon.com" -site:"www.aliexpress.com" -site:"www.alibaba.com"	8	0
14	Intervention systems, narrower search	"blind spot intervention system" OR "blind-spot intervention system" OR "blind zone intervention system" AND ("truck" OR "heavy goods vehicle" OR "bus" OR "coach") -site:"www.amazon.com" -site:"www.aliexpress.com" -site:"www.alibaba.com" -"nissan"	173	0
15	Collision detection/assistance/warning/ avoidance systems	intitle:"blind spot collision" OR intitle:"blind-spot collision" OR intitle:"blind zone collision" AND ("truck" OR "heavy goods vehicle" OR "bus" OR "coach") -site:"www.amazon.com" -site:"www.aliexpress.com" -site:"www.alibaba.com"	301	0
16	Side blind spot systems	intitle:"side blind zone alert" OR intitle:"side-view assist" OR intitle:"side assist" OR intitle:"side object detection" AND ("truck" OR "heavy goods vehicle" OR "bus" OR "coach") -site:"www.amazon.com" -site:"www.aliexpress.com" -site:"www.alibaba.com"	10100	2
17	Rear blind spot systems	intitle:"rear automatic braking" OR intitle:"reverse automatic braking" OR intitle:"rear parking assist" OR intitle:"rear cross traffic alert" OR intitle:"reversing detection" OR intitle:"rear object detection" AND ("truck" OR "heavy goods vehicle" OR "bus" OR "coach") -site:"www.amazon.com" -site:"www.aliexpress.com" -site:"www.alibaba.com"	3310	3
18	Front blind spot systems	intitle:"front blind spot" OR intitle:"front blind zone" OR intitle:"front blind-spot" AND ("truck" OR "heavy goods vehicle" OR "bus" OR "coach") -site:"www.amazon.com" -site:"www.aliexpress.com" -site:"www.alibaba.com"	199	0
19	Industrial vehicles	"blind spot warning" OR "blind spot detection" OR "blind spot assistance" OR "blind spot monitor" OR "blind spot information" OR "blind spot collision detection" AND ("crane" OR "mining" OR "front loader" OR "excavator") -site:"www.amazon.com" -site:"www.aliexpress.com" -site:"www.alibaba.com"	516000	11
20	Front blind spot systems, moving off information systems	"moving off information system"	1720	9

Appendix C Evaluation criteria template

external questionnaire				Description
Evaluation category	subcategory	specification	observation	Description
System identifier	OEM ID	name		System name, as given by manufacturer
		modular (y/n)		Is the system modular (y/n)
		model		(sub)system/module manufacturer ID
		OEM vs retrofit		Is the system supplied as retrofit option, or as part of a vehicle
	Inventory ID			SWOV internal ID (not based on manufacturer-supplied information)
Operational Design Domain	vehicle classification	rigid vehicles (y/n)		Applicable for vehicles that consist of one rigid body (e.g., box truck)
		articulated vehicles (y/n)		The system is applicable for vehicles that consist of two rigid bodies connected with an pivoting joint (e.g., tractor/trailer-combination, accordeon bus)
		other vehicles (y/n)		The system is applicable for other vehicles; e.g., excavators, cranes, mining vehicles.
		UNECE vehicle classifications		The system is applicable for these UN/ECE vehicle classifications
	blind spot classification	system class		BSIS, MOIS, REIS, … (only if given by manufacturer)
		monitoring direction		The system is intended to monitor the following general directions: front, passenger side, rear, driver side
		UNECE blind spot classifications		The system is compliant with these UN/ECE blind spot classifications
	functional	object detection type		The system is suitable to detect stationary and/or moving objects
		VRU (y/n)		The system is stated to detect VRU
		maneuvers		The system is active for particular maneuvers
Implementation	general	sensor type(s)		Type of sensor (e.g., ultrasonic, radar, etc.) - note all sensors included, separate properties with semi-colon, decimals with point and comma for separate values of one property
		sensor protection rating		Sensor IP-rating
		ECU protection rating		ECU IP-rating
		number of sensors		The number of sensors comprised by a system
	power system	vehicle/stand-alone		Is power to the system supplied by the vehicle battery or an external battery
		operating voltage		Safe operating voltage (range; Volts)
		current consumption		Current consumption (Ampere)
		power consumption		Power consumption (Watts)
	sensor description	individual sensor vs. Array		Description applies to individual sensors or array
		sensor horizontal FOV		Horizontal Field-Of-View covered by complete system (degrees)
		sensor vertical FOV		Vertical Field-Of-View covered by complete system (degrees)
		sensor FOV accuracy		Possible constant error in Field-Of-View (degrees)
		sensor FOV precision		Possible variable error in Field-Of-View (degrees)
		sensor range width		Maximum lateral coverage of Field-Of-View (meters)
		sensor range depth		Maximum depth of Field-Of-View (meters)
		sensor range accuracy		Possible constant error in lateral/depth coverage (meters)
		sensor range precision		Possible variable error in lateral/depth coverage (meters)
	object properties	minimal object resolution (in deg FOV)		Minimal object size required for detection (degrees)
	HMI	warning vs intervening		Does the system provide drivers/other road users with a warning, or does it provoke an active response from the vehicle?
		warning type		Type of warning (e.g., auditory, visual, tactile, etc.)
		staged warnings		Does the system fea
		intervention type		Type of intervention (e.g., braking, force feedback, etc.)
		malfunction indicator		Does the system feature an integrated malfunction indicator?
	System integration	integrated vs. Stand-alone		Does the system integrate with vehicle systems, or does it work completely indepen
		connection		How is the system connected to the vehicle? CAN…
		wireless (y/n)		Is the system connected by wire or wirelessly?
		input		Which vehicle data is required by the system?
	Reliability	lifetime		Expected lifetime of system
		maintenance		Required maintenance
	compliance with standards			Any standards the system adheres to, noted by manufacturer
Scientific validity	classifier evaluation	sensitivity		Proportion of true positives obtained in empirical tests
		specificity		Proportion of true negatives obtained in empirical tests
		qualitative statements		Other evaluations of system performance based on empirical tests
	test protocol	number of observations		Number of observations collected in empirical tests
		blind zone coverage		FOV sampling granularity of empirical tests
		ambient conditions		Which ambient conditions were included in tests (e.g., lighting conditions, temperature, vibrations)
		usability tests		Were usability tests performed with drivers?

Appendix D Cover letter information request

Dear sir/madam,

SWOV Institute for Road Safety Research has been commissioned by Shell Global Solutions International B.V. to create an inventory and qualitative comparison of commercially available Blind Spot Monitoring Systems. As Blind Spot Monitoring Systems, we consider any system that actively warns drivers of buses, heavy goods vehicles and other large mobile equipment (e.g., mining vehicles), of objects and vulnerable road users present in the vehicle's blind spots. The scope of this inventory includes systems integrated in new vehicles, as well as retrofit options. Among the results of our search queries was the following system that, we presume, is manufactured by your company. Please let us know if you are not the original manufacturer of these systems.

1. [System name]

We would like to include this system in the inventory. To be able to conduct a comprehensive review, we require information on system implementation and performance. With this letter, we wish to request documentation on the listed system.

What information is required?

The review is intended to weigh system features against costs and availability. The provided information should therefore include details of the implementation (e.g., sensor(s); HMI), assessments of system performance, and some indication of unit costs. Unit cost may depend on the type and number of vehicles for which you are able to supply systems. Please can you provide us with an indicative quote for the following hypothetical business cases?

a) 1,000 rigid trucks (length: 12m) over a 5-year period;
b) 10,000 tractor/semitrailer combinations (length: 16.5m) over a 5-year period;
c) 1,000 cranes (no particular length; the vehicle has to be able to drive on public roads), delivery starting in 2024.

Of particular interest is also information on the scientific test protocol. Ideally, provided information allows us to complete the fields in the template attached to this inquiry. Please note that the template is provided as an example. We do not ask you to fill out the form for us, but will attempt to do so using any information provided.

Data management

We will extract details from any provided manuals, reports, etc., to fill out the attached template. This system will then be included in a table, which will be the grounds for our qualitative review. We realize that availability of information may vary, and intend to be lenient with regards to missing fields. The table will be made available as part of a public report, but source materials will not be shared with any other party. Quotes for unit costs will *not* be made public. Instead, a qualitative indicator based on unit cost ranges will be used in the assessment and reporting. Other sensitive information may be redacted from the public report upon specific request.

Time frame

The report is due by April 2023. Therefore, we kindly ask you to provide information at your earliest convenience, but no later than [date]. We cannot guarantee that information provided after this deadline can be included in the review.

Any other questions?

For more information, please feel free to contact us. We would be happy to provide you with further details.

Thank you for your consideration,

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Appendix E Overview of commercially available systems

This appendix describes the operational design domain, implementation, scientific validity, unit cost, and availability of blind spot monitoring systems for the 35 companies found to provide systems eligible for consideration. Findings for systems are presented per manufacturer, and are presented in alphabetical order.

E.1 Autel

Autel did not respond to contact requests. The following information was extracted from an installation manual available on the product website.

E.1.1 Blind Spot Assist ATS100

Operational Design Domain

The system is intended to warn drivers of heavy commercial vehicles such as trucks and buses or VRUs moving at >5km/h through the vehicle blind spot, while the vehicle has a speed below 30km/h. It is compliant with UNECE R151.

Implementation

The system features a single radar sensor with an IP69K protection rating and a stand-alone monitor. The system requires a supply voltage of 12 or 24V and consumes 6.5W of power.
The radar has a horizontal FoV of 180°; the vertical FoV is not specified. The area monitored by the system is stated to extend 40m to the front and 40m to the rear of the sensor (i.e., a total of 80m) and has a depth of 4.5m. Minimal object resolution is not unambiguously specified. However, maximum range for detection of a person is specified as 40m. Assuming a person width of 40cm, this would translate to a resolution of approximately 0.06°, which is approximately a factor 10 better than comparable systems, and therefore is not plausible.
The system features a display which shows a top view of a rigid truck and several warning lights. The monitored area is divided into three different priority zones: an upper zone (2.5m in front of the vehicle front), a middle zone (2m in front of the vehicle front to 7m behind the vehicle front), and a lower zone (7 to 30m behind the vehicle front). If several objects are in the upper, middle or lower zone at the same time, priority is given to the middle, the lower, and then the upper zone. Warnings are issued at three different levels.
A level 1 warning is given when the steering wheel angle is less than 30° and an object enters the warning area. In this case a section of the warning lights in the display will light up.
A level 2 warning is given when the vehicle is turning right and the steering wheel angle is more than 30° or the turn signal is turned on, and the vehicle and a detected object are expected to collide. In this case a section of warning light LEDs will start flashing.
A level 3 warning is given when the vehicle turns right and the steering wheel angle is greater than 30° or the turn signal is turned on, and the vehicle and a detected object are expected to collide. In this case, warning LEDs in the display will flash, as for a level 2 warning, but an auditory warning is given as well.

The system connects to the vehicle via CAN bus and requires information on vehicle speed, steering wheel angle, yaw rate, longitudinal acceleration and lateral acceleration.

Scientific Validity

System sensitivity nor specificity were not explicitly specified. However, the system website claims that the system has a ‘low false alarm rate’.

Unit Cost

No data on unit cost were available

Availability

Data on system availability could not be obtained.

E.2 Advantech

Advantech responded to our inquiries, and pointed out that one of the systems returned by our search would be phased out in the near future (TREK-134); the system is therefore not included in this inventory.

E.2.1 TREK-154 Intelligent Blind Spot Detection Module

Operational Design Domain

The TREK-154 system is a modular camera system suitable for rigid and articulated vehicles as well as off-motorway vehicles. By combining multiple cameras, the system can monitor the front, both sides and the rear blind spots of the vehicle. It is compliant with UNECE Regulations R151, R158, R159 (provided sensors are installed to monitor relevant directions).
It can detect stationary and moving objects including VRUs.

Implementation

The system makes use of cameras with a protection rating IP69K. Depending on the application, either four (rigid vehicles) or six (articulated vehicle) cameras are used.
Cameras operate on voltages between 10-36V, and consume 4W of power. Each camera features a horizontal FoV of 180± and an effective range of 12m.
The HMI provides visual warnings by urgency zone. Details on the nature of the warnings are not available.

Scientific Validity

Data on scientific validity are not available.

Unit Cost

A four-camera solution for rigid and off-motorway vehicles has a €€€ unit cost; a six-camera solution also has a €€€ unit cost.

Availability

Data on system availability is not available.

E.3 Bendix

Bendix did not respond to contact requests. The following information was extracted from a description of a system intended for trucks on the product website.

E.3.1 Blindspotter

Operational Design Domain

The Blindspotter system is a Side Object Detection system, available as retrofit solution. It is intended for use with trucks, tractors and buses, and detects moving vehicles in the blind spot.

Implementation

The system makes use of a single radar sensor. Data on protection rating and power consumption are not available. The sensor features a 150° FoV, which covers a range of 12.2m wide by 3m deep at high speeds; which is narrowed down to 4m wide by 3m deep at low speeds. The speed threshold distinguishing high and low speed is not stated.
The system delivers staged warnings. An amber LED is lit when the system is active. Whenever a vehicle enters the blind spot, a red LED is illuminated. When the driver activates the turn signal whenever a vehicle is present in the blind spot, an auditory warning is issued as well.
The system connects to the vehicle over CAN bus.

Scientific Validity

Data on scientific validity are not available.

Unit Cost

Data on unit cost are not available.

Availability

Data on system availability are not available.

E.4 Blind Spot Monitor

Blind Spot Monitor produces several blind spot monitoring systems for commercial vehicles. The company provided information and manuals for the three systems described below.

E.4.1 77GHz millimeter wave radar obstacle avoidance early warning system

Operational Design Domain

The system is designed to detect objects on the front, rear, and side of HGVs as well as mining vehicles (based on imagery on the product website). The supplied information does not specify if moving objects are separated from static objects, nor if VRUs are among the detected objects. The system is available as a retrofit kit.

Implementation

The system uses a combination of a radar sensor (IP67 protection rating) for object detection and a camera sensor for a real-time view on an external display. All components are connected to a master control box (IP65 protection rating), which draws its power from the vehicle (operating voltage: 12-24V, power consumption: < 5W). The radar sensor has a horizontal FoV of +/- 60° and a vertical FoV of -2° to +8°. Its range is configurable and covers a maximum detection area of 8m by 40m, with a sensor range precision of 0.2m.
A three-staged warning based on proximity is used to warn the driver of the presence of objects in the detection zone. The first level warning (farthest) involves a flashing green light box around

the edges of the display (contrary to some other systems, the system does not appear to use an onscreen overlay to illustrate which object has been detected). The second level warning (middle distance) involves a flashing yellow box and a 'beep' with a low repetition rate. Finally, the third level warning involves a red flashing box and a continuous 'beep' sound. The distance of the detection areas corresponding with each warning stage can be configured.
For error-free working operation, the company advices to recheck the system after a long trip, to recheck the wiring, radar position, and shape at regular intervals, and to orient the radar using the supplied calibration techniques after every six months.

Scientific Validity
Numerical data on scientific validity are not available. The supplied information advises to keep the forward collision avoidance system radar away from locations with strong magnetic interference to prevent false object detection.

Unit Cost
A one-radar solution including a display has a € unit cost; a two-radar solution including a display has a €€ unit cost.

Availability
Data on system availability are not available.

E.4.2 Truck blind spot detection 24G 11RS

Operational Design Domain
The system is designed to support drivers with lane changes by warning them if 'moving objects' are present on the co-driver's side of the vehicle. Rigid trucks of the N2 and N3 categories appear to be part of the operational design domain. The supplied information and imagery on the product website did not indicate that the system works for articulated vehicles, nor could it be inferred if VRUs are detected. The system is available as retrofit kit.

Implementation
A single radar sensor with a horizontal FoV of 110° is used to detect moving objects in a detection zone of maximally 3m (from the side of the vehicle) by 10m (in rear direction, measured from the front of the vehicle). The radar sensor has an accuracy of <0.18m and precision of 0.5m. A red warning light in the cabin is illuminated when a moving object is detected in the detection zone. Connected to the vehicle's power supply, the power consumption is <2W at 12V. The system does not require any other connection with the vehicle (e.g., stand-alone). The radar sensor has an IP67 protection rating.
The system can be expanded with a camera and a display, such that the camera view is activated once the radar sensor detects an object.

Scientific Validity
Numeric data on scientific validity are not available. The manual does mention that the system may generate a false alarm in case of heavy rain when the vehicle is stationary. Also, several cases in which the system may not alert the driver are listed:

- "The vehicle is located in a blind zone behind the side of the adjacent lane on the right and remains relatively at the same speed for a long time."
- "The adjacent lane in which the vehicle is located is extremely wide and exceeds the radar signal calculation range."
- "When crossing a hill or the top of a mountain pass."
- "When water droplets completely cover the radar housing in heavy rain, it will reduce the detection sensitivity and effect."

Unit Cost

A system without camera and display has a € unit cost. Combined with camera and display, the unit cost of the system still falls in the € category. A MOQ for the provided quotes was specified.

Availability

Data on system availability are not available.

E.4.3 Truck blind spot detection 79G 01R

Operational Design Domain

The system assists truck drivers (vehicle categories N2 and N3) with lane changes and turning by warning if objects are in the detection zone on the co-driver's side of the vehicle. Based on imagery on the product website, the system appears to function with rigid and articulated trucks. The system has a high-speed mode (driving speed >18km/h) in which it only detects moving objects with a moving speed exceeding 10km/h, and a low-speed mode (0-18km/h) in which it detects moving objects as well as stationary objects. The supplied information does not specify whether the system is able to detect VRUs. The system is available as retrofit kit.

Implementation

A single radar sensor with a horizontal FoV of 150° is used to detect objects in a detection zone with a coverage alongside the vehicle of +7m to -7m relative to the sensor position. The lateral coverage is 0.2-3.5m in the high-speed mode and 0.2-1.5m in the low-speed mode. Objects are detected with an accuracy of 0.1m and a precision of 0.5m. A red warning light in the cabin is illuminated and a buzzer provides an auditory alarm when an object is detected in the detection zone. System malfunctioning is indicated with a self-inspection light, which, upon switching on the vehicle, turns on for 1 second and then turns off. The system is connected to the vehicle's power supply, operating with a voltage of 12-24V, with a power consumption <5W. The system does not require any other connection with the vehicle (e.g., stand-alone). The radar sensor has an IP67 protection rating.

Scientific Validity

Data on scientific validity are not available.

Unit Cost

The system has a € unit cost for a specified MOQ.

Availability

Data on system availability are not available.

E.5 Brigade

Brigade did not respond to contact requests beyond confirmations that the inquiry had been received. The following information was extracted from descriptions on the product websites.

E.5.1 Backsense

Operational Design Domain

The Backsense system is suitable for rigid and articulated vehicles, as well as for off-motorway vehicles. It detects stationary and moving objects including VRU. The system is designed with reversing in mind, but can be used to monitor other directions as well, depending on sensor mounting location.

Implementation

The backsense system makes use of a radar sensor and stand-alone ECU display/buzzer device. It can be extended with a camera and monitor. The sensor has protection rating IP69; the ECU has protection ratings IP68 and IP69K.
The system operates for voltages between 9-32V and currents of 0.92-0.25A, respectively; consuming about 8W of power.
The radar sensor has a FoV of 120°(±0.25°) horizontal by 12°(±0.25°) vertical, and a range between 2-10m wide by 3-30m deep, which can be set to desired specifications.
The HMI alerts drivers by means of staged visual-auditory warnings. There are 5-levels that correspond to detected object proximity; green, light green, yellow, orange and red LEDs, combined with 1.5Hz, 2, 2.5Hz, 3Hz, and constant beeps; generating an incrementing sense of urgency.
The system connects to the vehicle by can bus and requires a power and ground connection as well as a trigger connection (e.g., reversing).
The system is compliant with standards: CE; UNECE R10; ISO 16750; ISO 13766; EN 13309; FCC.
The system is configurable by computer over a USB connection.

Scientific Validity

Data on scientific validity are not available.

Unit Cost

Data on unit cost are not available.

Availability

Data on system availability are not available.

E.5.2 Ultrasonic Obstacle Detection

The Ultrasonic Obstacle Detection includes six general solutions: Backscan, Sidescan and Sidescan Flex, Frontscan, Cornerscan and Stepscan, and further variations of each solution appear to be available. These solutions are variations of the same general methodology, but monitor different sides of the vehicle. As such, they are discussed jointly. By means of an additional module, up to two systems can be combined, and merged with a camera view.

Operational Design Domain

Ultrasonic Obstacle Detection systems are suitable for rigid and articulated trucks as well as off-motorway vehicles. The Backscan system is intended to monitor the rear of the vehicle; the Sidescan and Sidescan Flex systems monitor the side of the vehicle; Frontscan monitors the front of the vehicle; and the Cornerscan and Stepscan systems monitor a front corner and specifically the step to facilitate climbing into the cabin of the vehicle. The systems are suited to detect both stationary and moving objects, including VRUs.

Implementation

The systems make use of ultrasonic sensors to detect objects. Protection ratings for the ECU and sensor are IP69K and IP68 respectively. The systems combine four sensors, except for the Cornerscan (3) and the Stepscan(2).
The operating voltage range is 10-32V, and current consumption at 12V is 0.2A. Power consumption is 2.4W.
Individual sensors have a FoV of 90° horizontal by 60° vertical, and a range of up to 2.5m.
The HMI provides three levels of combined visual-auditory warnings on a stand-alone unit. When objects are detected in the 1-2.5m range, a green LED lights up and a 0.5Hz beep is generated; for 0.6-1m a yellow LED lights up and a 0.125Hz beep is generated. When objects are detected in the 0-0.6m range, a red LED lights up and a continuous beep is generated.
The system requires a power and ground connection with the vehicle only.

Scientific Validity
Data on scientific validity are not available.

Unit Cost
Data on unit cost are not available.

Availability
Data on system availability are not available.

E.6 Bosch

Bosch offers separate sensors as well as modular systems that can be adapted to the wishes of customers. The systems can include multiple ultrasonic sensors, radar sensors, and cameras. Solutions of interest were Turn Collision Warning, Blind Spot Detection, and a Moving-Off Information System for heavy commercial vehicles, and Ultrasonic Sensor System for off-motorway applications. Different solutions appear to be linked to different contacts at Bosch. Sufficient data for an evaluation could only obtained for the (prototype) Off-Highway Vision System. Repeated requests for information on other solutions were not answered. Because information for other systems available on web-pages is limited to specifications of the sensor used, these systems could not be included in the inventory.

E.6.1 Off-Highway Vision system

Operational Design Domain
The system is designed for off-motorway vehicles, such as forklifts, and is intended to detect objects such as large rocks or people around the vehicle.

Implementation
The Off-Highway Vision system combines four radar units, one ultrasonic sensor and a surround camera system, and fuses the information collected by these sensors on a display; highlighting detected objects within the camera image.
The ultrasonic sensor has IP ratings of IP6KX and IPX9K; the radar system has an IP rating of IP6k9K and the cameras have an IP rating of IP6K9K. The ECU protection rating is IP6K9. An additional unit for processing camera images has protection rating IP5K.
Each sensor operates for different voltage ranges, but all work for voltages between 9-16V. Power consumption is specified only for the camera system, which consumes 14W of power.
An individual ultrasonic sensor features an FoV of 140° (±70°; horizontal) by 70° (±35°; vertical) and a range of 5.5m. Minimal object resolution, at 5.5m is approximately 0.78°. This resolution is calculated from the datasheet, which notes detection of a 7.5cm diameter tube at 5.5m. The ultrasonic sensor supports detection of up to twenty objects. The radar sensor consists of a near- and far-range antenna. The near-range antenna offers a horizontal FoV of 85.2° (±42.6°) at a range of 29m, which tapers off to 42°(±21°) at a range of 78m, with a vertical FoV of 15° at a range of 50m (-4:11°, with 0° presumably corresponding to Earth-horizontal); The far-range antenna has a horizontal FoV of 20°(±10°) at 60m, which tapers off to 12° (±6°) at 160m. The vertical FoV is 13°(-7.5:5.5°) at 160m. Two variations of the radar are available, which allow detection of up to either 40 or 48 objects. Individual cameras offer a horizontal by vertical FoV of 185° × 120°. Multiple camera images are merged by an ECU to create a 360° FoV.
The system only provides visual warnings, by highlighting detected objects as overlay in camera images presented on a monitor.
Ultrasonic and radar systems connect over vehicle CAN bus; the camera system via an automotive ethernet connection. Operating voltages differ somewhat between systems with the

ultrasonic sensor needing either 12 or 24V; the radar working with a range of 7-18V and cameras 9-16V.
This system requires information on vehicle speed and yaw-rate via CAN connection.

Scientific Validity
No data on either of the categories of scientific validity were available.

Unit Cost
Unit costs for individual radar and ultrasonic sensors fall in the €€ category. A camera system has a €€€ unit cost, which increases when used as a retrofit solution. By combining the prices of the individual components, an Off-Highway Vision System would have a €€€ unit cost.

Availability
Systems are available in EU, USA, CA, JP, AUS, and NZL markets and are typically in stock. Lead times depend on order quantities.

E.7 CandidTech

The company acknowledged our contact request, but has not responded since. Therefore, the following information was extracted from a description on the product website.

E.7.1 Bus All-around Blind Spot Detection System

Operational Design Domain
The system is designed to inform bus drivers of (moving) obstacles around their vehicle, including VRUs. Based on the product website, the system appears to assist drivers when turning, changing lanes, and reversing (specifically: rear cross-traffic alerts). The system is available as retrofit kit.

Implementation
A combination of four radar sensors and 4 cameras is used around the vehicle. On each side of the vehicle two radar sensors (protection rating: IP67) are located near the rear corner and between the front wheel and the front of the vehicle. The radar sensors have a FoV of 120° horizontally and 30° vertically. Objects are detected with a precision of ±0.65m. Imagery on the product website suggests that the size and shape of the detection area of the radar sensors depends on their application. For turning, the detection area is a cone of 8m long alongside the vehicle (measured rearwards from the front radar sensor) with a maximum width of 3m. The rear radar sensors are used for lane change alerts, spanning a cone of 50m behind the vehicle on either side, with a maximum width of 3m. For reversing, the rear cross-traffic detection areas span 3m behind the vehicle by 20m to the side on either side of the vehicle. The imagery surprisingly suggests that the system does not provide warnings for road users directly behind the vehicle. An LED lamp is illuminated when an object is detected. In case the driver has used the turn indicator, the LED lamp flashes and a buzzer provides a ‘beep’.
The cameras are connected to a display to provide a real-time view of a blind spot, once triggered by a radar sensor. Cameras mounted on the front and rear of the vehicle have a (presumably horizontal or diagonal) FoV of 150°. Cameras mounted on the top edge of the side of the vehicle have a (presumably horizontal or diagonal) FoV of 190°.
The system draws its power from the vehicle’s battery (operating voltage: 9-16V, current consumption: <1100mA at 12V). Besides power supply, the system requires turn signal and reverse gear information from the vehicle. The system is compliant with ISO17387 (performance requirements and test procedures for lane change assistance systems).

Scientific Validity

On the product website, CandidTech claims that the system has a sensitivity of 95%. No details are provided on how this measurement was obtained (but possibly this relates to compliance with ISO17387). No details on specificity are provided.

Unit Cost

Data on unit cost are not available.

Availability

Data on system availability are not available.

E.8 CAT

CAT features two systems on their website that appear to be within the scope of this inventory, i.e., the CAT Detect – Object Detection and Rear Object Detection for wheel loader systems. They did not respond to contact requests. The following information was extracted from system descriptions on the product websites.

E.8.1 CAT Detect – Object Detection

Operational Design Domain

The system is intended for off-motorway vehicles. It monitors the front and rear of the vehicle as well as the area within the vehicle turning radius. It is active at low speed, and detects both stationary and moving objects, such as vehicles; VRUs are not mentioned.

Implementation

The system combines radar and camera sensors. The HMI provides multiple proximity warning levels and can provide auditory and visual warnings. It also automatically switches camera view on a display to any area in which an object is detected. No other information on system implementation is available.

Scientific Validity

Data on scientific validity are not available.

Unit Cost

Data on unit cost are not available.

Availability

Data on system availability are not available.

E.8.2 Rear Object Detection for wheel loaders

Operational Design Domain

The system is intended for off-motorway vehicles. It monitors the presence of objects in the rear blind spot of the vehicle and is active when the vehicle is in neutral with parking brake disengaged or when reversing. The types of objects detected are not specified.

Implementation

The system combines radar and camera sensors, and monitors an area of 6m wide by 16m deep. The HMI provides staged warnings at five proximity levels in the form of bars on a display, combined with beeps that increase in frequency with object proximity. The system is also stated to feature status indicators, but their function is not explained. No other information on system implementation is available.

Scientific Validity

A qualitative statement on classifier behaviour is given, namely that warning levels are related to ground speed of the loader to reduce nuisance alarms. No other data on scientific validity are available.

Unit Cost

Data on unit cost are not available.

Availability

Data on system availability are not available.

E.9 Cisbo

Cisbo did not respond to contact requests. The following information was extracted from a description of a truck system on the product website.

E.9.1 C52 Truck Blind Spot Radar Detection System

Operational Design Domain

The system features dual sensors that allow monitoring of objects in the blind spot on the driver and passenger side of the vehicle

Implementation

The system uses two radar sensors, mounted on both sides (driver, passenger) of the vehicle. Operating voltage range is 9-36V.
Each sensor has a reported horizontal FoV of between 90-120°. The area monitored by the system is indicated to extend 15m to the rear of the sensor and has a depth of 3m. Minimal object resolution is not specified.
The HMI includes dual LEDs to be mounted in the vehicle cabin, on both A-pillars, and a buzzer. No information is available on how warnings are issued when an object is detected.

Scientific Validity

Data on scientific validity were not available.

Unit Cost

Data on unit cost were not available.

Availability

Data on system availability were not available.

E.10 Continental

Continental responded to our inquiries and provided information for the RightViu system.

E.10.1 RightViu

Continental offers three systems (Blind Spot Detection, Left-Turn Assist, and RightViu), which make use of the same radar sensor.

Operational Design Domain

The Left-Turn Assist is marketed for use in agricultural vehicles and is therefore not within the scope of this inventory. The RightViu system is operational at vehicle speeds up to 30km/h and warns drivers of moving objects (Vulnerable Road Users) present in the blind spot. Although no documentation was obtained for the Blind Spot Detection System, the webpage for this system suggests that it is instead operational at higher speeds. Systems can be used with rigid vehicles, articulated vehicles, and other vehicles alike and it is suitable for detection of both stationary and moving targets, and is marketed as a solution to detect VRUs during turning manoeuvers.

Implementation

The system uses a single radar sensor, which is mounted at the outside rear-view mirror on the passenger-side, at least 2m from ground level. The sensor has IP ratings IP6K9K and IP6K7, the ECU has an IP rating of IP52. It operates on either 12V or 24V and consumes 6.6W of power.
The sensor comsists of a near- and far-range antenna. The near-range antenna offers a horizontal FoV of 120°(±60°) at 10m, which tapers off to 80°(±40°) at 70m. The far-range antenna has a narrower FoV, of about 18°(±9°) at 70-150m, which tapers off to 8°(±4°) at 250m. The vertical FoV is not specified separately for the two antennas, but is stated to be 20° at 70m, tapering off to 14° at 250m.
The area monitored by the system is stated to extend 4m to the front and 14m to the rear of the sensor mounting position. The manual narrows down this area to an area starting at 0.9m from the side of the vehicle, extending up to 2.5m deep, and 6m wide[5].
The minimal object resolution is 1.6° for the far range sensor, but increases with eccentricity relative to the sensor line of view. It is stated to be 3.2° at 0° eccentricity, 4.5° at 45° and 12.3° at 60° eccentricity.
The system HMI consists of a light and buzzer mounted on the A-pillar of the vehicle. It provides warnings to the driver when an object is detected, by turning on the light for as long as the object is in the blind spot, and by buzzing three times whenever a new object is detected.
The system connects to the vehicle over CAN bus and requires vehicle information on speed, steering angle, and activation of the right Turn Signal Indicator (TSI).
Lifetime is specified as 10,000 hours or 10 years. It is recommended to inspect the system before each use and to clean it when necessary, and check alignment once a year.

Scientific Validity

No data on either of the categories of scientific validity were available.

Unit cost

Unit costs fall in the €€ category. Pricing was not explicitly related to a MOQ.

Availability

Delivery times depend on order quantity, and can only be specified when on order is placed.

E.11 CUB

The company acknowledged our contact request, but did not provide information by the time of writing the present report. The product website was unavailable on March 24, 2023, and still found to be unavailable on March 30. Therefore, it is uncertain whether the system can still be supplied. The following information was extracted from a description on the product website as registered before March 24.

5. Given a sensor mounting height of 2m, the smaller range corresponds to an approximate sensor FoV of 112.6° horizontal by 27.1° vertical.

E.11.1 Blind Spot for Commercial Vehicles

Operational Design Domain

The system appears to be designed for rigid light trucks (category N2). The system warns when moving obstacles are detected (including VRUs) when turning, reversing (specifically: rear cross-traffic alerts), and changing lanes. The system is available as retrofit kit.

Implementation

One or more radar sensors are used (amount not specified) to detect objects. The detection area has a width alongside the vehicle of approximately 23m for turning and lane changes, and approximately 18m for rear cross-traffic detection. Driving speed, turn signal and reverse gear information are used to determine which application (blind spot detection, lane change assistance, rear cross-traffic alert) should be activated. According to the product website, blind spot detection is surprisingly activated when the driving speed *exceeds* 24km/h (typically assistance for turning is activated at driving speeds *below* 24km/h), and object detection results in an illuminated warning lamp. For lane change assistance, an auditory warning is presented and the warning lamp with the corresponding turn signal will flash when a vehicle is within the detection area, or if a vehicle is detected approaching at high speeds resulting in an impact in less than 2 seconds during the lane change. A rear cross-traffic alert is presented as an auditory warning, as well as flashing the warning lamp when an approaching pedestrian or vehicle is detected resulting in an impact in approximately 2 seconds.
The system is compliant with ISO17387 Type 3 (performance requirements and test procedures for lane change assistance systems).

Scientific Validity

Data on scientific validity are not available, but scientific validity may be derived based on requirements described in ISO17387.

Unit Cost

The system has a €€ unit cost.

Availability

Data on system availability are not available.

E.12 Dometic

The company did not respond to contact requests. The following information was extracted from a description and manuals on the product website.

E.12.1 PerfectView CAM1000

Operational Design Domain

The PerfectView CAM1000 is designed as turning assistant for rigid and articulated HGVs. It distinguishes between moving objects (including pedestrians, cyclists and wheelchair users) and static objects on the co-driver's side of the cabin. The CAM1000RHD is designed specifically for right-hand drive HGVs. The system is available as retrofit kit.

Implementation

Objects are detected using a single camera sensor (protection rating: IP69K) mounted above or near the door of the co-driver. The detection zone is configurable, depending on the mounting height. Mounted at a height of 3m from the ground, the detection zone spans 15m alongside the vehicle (including 2-3m in front of the vehicle) up to 4m from the side of the vehicle. The camera is connected to a display inside the cabin, providing a real-time view on the detection zone. Objects within the detection zone are signalled by a colour overlay on the display as well as by an auditory alarm. The system provides feedback in case of malfunction (e.g., no detection available, sound inactive). The system works up to a driving speed of 40km/h. Driving speed is determined using a built-in GPS receiver, which means that the system is stand-alone, other than power supplied by the vehicle (voltage range: 10-36V, power consumption < 6W). The manual does not state an expected lifetime of the system, but it does note that the statutory warranty period applies (this may be region-dependent). Maintenance involves occasional cleaning and regular checks of the cables. The system complies with standards ECE R10, ISO16750-3, ISO 16750-4, SAE J2527, E CISPR 25, ISO 7637-2, and FCC Part 15b. Furthermore, the system is compliant with the Direct Vision Standard and is eligible for funding in Germany through the "De-minimis" funding programme.

Scientific Validity

Numerical data on scientific validity are not available. According to the manual, the system does not detect hidden objects, the detection of objects in darkness and/or strong shadow is limited, and objects with a shape similar to a human body may generate a detection indication.

Unit Cost

Unit costs fall in the €€€ category.

Availability

Data on system availability are not available.

E.13 Durite

Three blind spot detection systems by Durite were identified. Other than auto-replies, the company did not respond to contact requests. The following information was extracted from a description on the product website.

E.13.1 Blind spot detection system

Operational Design Domain

Durite’s ‘Blind spot detection system’ can be mounted at the front, rear and side of rigid and articulated vehicles (categories M2, M3, N2, N3). The system warns drivers about objects when reversing, turning, manoeuvring and when changing lanes. The product manual does not explicitly describe whether vulnerable road users are among the detected objects. Implicitly, the statements that the sensor can detect people and that alerts outside the vehicle can inform cyclists and pedestrians suggests that VRUs are detected. The system is available as retrofit kit.

Implementation

An array of ultrasonic sensors (protection rating: IP68) is connected to an ECU (IP69K). Individual sensors have a horizontal FoV of 90°, a vertical FoV of 60°. Imagery in the product manual suggests that four sensors are required for front-, side- and rear-mounting, and three sensors are required for corner-mounting. Combined, the array of sensors covers a configurable detection area with a depth of maximally 1.5m (precision: 0.1m), divided into three zones. In the first zone (1.5-1.0m) a green LED flashes at 1Hz and a ‘beep’ sound is repeated at a rate of 1Hz. In the second zone (1.0-0.6m) an amber LED flashes at 4Hz and a ‘beep’ sound is played at a 4Hz rate. In the third zone (0.6-0.0m) a red LED flashes at 8Hz and the ‘beep’ sound is now played continuously. Connected to the vehicle’s battery, the system runs on 12V or 24V, with a current and power consumption of 200mA and 2.4W at 12V, respectively. Optionally, a trigger module may be

connected so that reverse gear, driving speed, and turning indicator information dictate which system (front, rear, side) should be activated.
The system includes a self-check function on start-up, where the ECU will beep once for every faulty sensor. The product manual recommends regular cleaning of the sensors.

Scientific Validity

Numeric data on scientific validity are not available. Regarding sensitivity, the product manual states that snow or dust can reduce efficiency. In the event of washing with high-pressure water jets, the sensors could temporarily lose part of their sensitivity, which will return once the water has completely evaporated. Furthermore, smooth slopes may remain undetected and the sensors may not detect any sponge-like obstacle as the ultrasonic wave may be absorbed. Regarding specificity, the product manual shows that the driver can tell the system to 'learn' to ignore a known false alarm (e.g., a tow bar at the back of a truck, which is continuously detected).

Unit Cost

Data on unit cost are not available.

Availability

Data on system availability are not available

E.13.2 Reversing sensor system

The 'Reversing sensor system' is marketed for reversing, but the manual is largely identical to the 'Blind spot detection system' described above, including that the system can be applied not only to the rear, but also to the side and front of the vehicle. Furthermore, the product website states that the ultrasonic sensors can detect objects up to 2.2m. However, the product manual states that the detection area can be configured to a depth of either 2.5m or 3.0m (as opposed to a depth of 1.5m for the 'Reversing sensor system'). Seeing that Durite did not respond to contact requests, these inconsistencies cannot be resolved in the present report. Apart from a larger horizontal FoV (120° vs. 90°) and a larger maximum depth (supposedly 3.0m vs. 1.5m), no differences compared to the 'Blind spot detection system' could be deduced.

E.13.3 Blind spot detection system with left turn speaker

Operational Design Domain

The system is mounted on the side of rigid and articulated trucks (categories N2, N3). The system warns drivers about objects when turning and when changing lanes. The product manual does not explicitly describe whether vulnerable road users are among the detected objects. Implicitly, the statements that the sensor can detect people and that alerts outside the vehicle can inform cyclists and pedestrians suggests that VRUs are detected. The system is available as retrofit kit.

Implementation

The system is intended as an add-on to Durite camera and display systems (for real-time visuals). An array of ultrasonic sensors is used for object detection. Box trucks require 4-8 sensors (spaced every 2.3m), whereas articulated trucks may require up to 12 sensors. The sensors have an IP68 protection rating, and cover a detection area of 1.8m deep. The detection area is divided into two zones. From 1.8m to 0.9m a yellow block is displayed on a Durite display. From 0.9m to 0m a red block is displayed, combined with a buzzer sound. The sound can be configured to only play in case the turn indicator is used. A red block is also shown upon turning on the vehicle (and therefore the system) in case the sensor is not in good condition (if it were, it would have resulted in a green block). Power is drawn from the vehicle's battery (operation voltage range: 10-32V, current consumption: <300mA). Additionally, the system makes use of turning signal information. A separate GPS module can be used to obtain speed information to configure the speed range in which the system is activated.

Scientific Validity

Numeric data on scientific validity is not available. However, the manual states several examples of false positives (e.g., reversing down a steep slope, pot holes) and false negatives (e.g., objects under the bumper). Furthermore, the product manual shows that the driver can tell the system to 'learn' to ignore a known false alarm (e.g., a tow bar at the back of a truck, which is continuously detected).

Unit Cost

Data on unit cost are not available.

Availability

Data on system availability are not available.

E.14 eXia

Information on the Active Sideguard system was generously provided by eXia.

E.14.1 Active Sideguard

Operational Design Domain

The Active Sideguard system is designed to warn drivers about the presence of other road users near the vehicle. The sensor strips of the system can be placed on the front, rear and/or sides of a vehicle. Depending on the placement, the system therefore assists with turning, reversing, lane changes, and (precise) manoeuvring. Examples on the product website mainly deal with turning. The system can discern moving objects from stationary objects and it can identify vulnerable road users (e.g., pedestrians, cyclists, e-scooters, wheelchair users, recumbent bicycles). The system is available as retrofit kit for rigid vehicles and for articulated semi-trailer combinations. Articulated buses are under validation. Furthermore, the system can be (and has been) implemented in construction transport, refuse collection, and waste processing.

Implementation

Objects are detected based on near-field interaction with a low-frequency electric field. Unlike radar, camera and ultrasonic sensors, the electrostatic sensing principle is not dependent on a line of sight. Thus, even when the line of sight is blocked, the Active Sideguard system can render a 3D image of its surroundings.
The field of view expressed in degrees does not apply to this electrostatic sensor, because it creates a 3D image without 'detection cones' found in other sensor types. Active Sideguard's detection field reaches from sensor mounting height down to road level, regardless of mounting height (maximum: 1.5m), such as to detect obstacles of various heights (including children and people who may have fallen to the ground). The detection zone covers an area spanning the entire length of the vehicle and a depth of 2.5m, in which objects can be detected with a diameter >0.1m and a height >0.35m.
Warning LEDs are illuminated when other road users are detected. If in addition a discernible intention to turn right is registered (e.g., using steering angle or use of the turn signal), the LEDs flash and a warning sound is played. Haptic feedback is optionally available.
The sensor strip and ECU (protection rating: IP67) are connected to the vehicle's power supply (operating voltage 17-30V), consuming relatively little power (<1mW) compared to other sensor types. Besides power supply, the system requires CAN bus information (e.g., steering angle, driving speed). For older vehicles there is an option to derive speed information from the tachograph, indicator information from the analogue contact input, thus omitting steering angle information. Active Sideguard hosts onboard diagnostics to determine if the system is (mal)functioning, and makes use of a fault-tolerant CAN-bus (compliant with ISO-11898-3).

The electrostatic sensor bar has an IP69 rating and requires no maintenance. According to eXia, the sensor surface has a water- and dirt-repellent coating, which, combined with engine vibrations, generates a self-cleaning effect. Furthermore, eXia states that Active Sideguard may endure occasional direct impacts without permanent damage, or the need to return to a workshop for accurate realignment of the sensor setup. The expected lifetime of the system is stated as more than 10 years.

Scientific Validity
No numeric data on scientific validity are available. However, eXia does state that laboratory tests and on-road tests are being and have been performed. Laboratory tests included sensitivity mapping at a 0.25m stepping resolution, yielding >1,000 observations (results not made available). In previous on-road tests (50 vehicles, 4 years duration), detection signals were correlated with visual camera cues. Furthermore, driver experiences were collected, both supervised and through a posteriori reporting. When asked if false alarms occur with the system, eXia responded with examples illustrating that feedback from drivers was used to optimise the detection algorithm to minimise nuisance alarms (in some cases for specific clients in specific areas). Currently eXia is performing another on-road test with 28 vehicles for a duration of 2 years.

Unit Cost
The following quotes for unit costs were obtained for all provided business cases. Each falls in the €€€ category.

Availability
The system is globally available. The rate at which the systems can be supplied has been specified and was said to be scalable.

E.15 Eyyes

Eyyes did not respond to contact requests. The following information was extracted from an information sheet on the product website.

E.15.1 CarEye Safety Angle

Operational Design Domain
The CarEye Safety Angle system is a retrofit BSIS for rigid vehicles, monitoring the passenger side of the vehicle. It is compliant with UNECE Regulation R151 and detects the presence of VRUs in the blind spot.

Implementation
The system makes use of a dual camera system which monitors an area 10m wide by 4m deep. It issues a warning via a signaller with yellow and red LED lights which can also issue an audio signal. The system has a self-diagnostic function and optionally connects to the vehicle CAN. No other information on the implementation is available.

Scientific Validity
Data on scientific validity are not available.

Unit Cost
Data on unit cost are not available.

Availability
Data on system availability are not available.

E.15.2 CarEye Safety Assistant

Operational Design Domain

The CarEye Safety Angle system is a retrofit BSMS for rigid vehicles, including off-motorway vehicles, monitoring the driver, rear, and passenger side of the vehicle. It is specifically intended to detect the presence of VRUs in the blind spot.

Implementation

The system makes use of three cameras which monitor a 270° area extending 9m to either side and the rear of the vehicle. It issues staged warnings via a signaller with yellow and red LED lights and a buzzer. When a VRU is in the FoV of the cameras, the yellow LED lights up; when the VRU is in close proximity to the vehicle and the AI deems a collision imminent, the red LED lights up and an auditory signal sounds. The system also features a self-diagnostic function. No other information on the implementation is available.

Scientific Validity

Data on scientific validity are not available.

Unit Cost

Data on unit cost are not available.

Availability

Data on system availability are not available.

E.16 FICOSA

According to their website, FICOSA supplies camera-based sensor technology for active and passive driver support. Image processing is used to warn the driver or to serve as input for a vehicle intervention. Although no specific blind spot detection systems are mentioned on the product website, additional imagery of supposed sensor detection areas suggests that FICOSA manufactures blind spot detection systems. FICOSA did acknowledge our contact request, but other than that, and despite reminding, no information was shared by the time of writing the present report. Therefore, no systems by FICOSA are described in this inventory.

E.17 Haloview

Haloview did respond to our contact request, but did not provide information on their solutions other than what is available on the product websites. Instead, they suggested that when further information on the functioning of their systems was desired, these could be purchased and tested by the customer. The following information was extracted from descriptions on the product websites.

E.17.1 Sophon AI System 720P HD Wireless Observation Camera

Operational Design Domain

From the applications suggested on the product website, it could be surmised that this system is intended for rigid vehicles, including off-motorway vehicles. Cameras can be mounted viewing any desired direction. Up to four cameras can be combined, potentially covering the full FoV. The system detects moving objects including VRUs.

Implementation

The system makes use of up to four cameras. The cameras have a protection rating of IP67 and can operate on battery power. Operating voltage range is 10-32V. The horizontal FoV of an individual camera is 120°, and objects are detected up to 10m from the camera.
The HMI warns the driver by changing the colour of a virtual box in the display corresponding to the warning zone from blue to red whenever an object is detected in this zone. An auditory alarm sounds simultaneously.
The system is stand-alone and only requires a power and ground connection, although it can function on battery as well. The camera connects to the display wirelessly.

Scientific Validity

Data on scientific validity are not available.

Unit Cost

Unit costs fall in the € category. This price is not related to a MOQ.

Availability

Data on system availability are not available.

E.17.2 SENS 3 Wireless ADAS System for Blind Spot Detection

Operational Design Domain

The SENS 3 system makes use of dual radar sensors and a stand-alone ECU/HMI unit which connect wirelessly. The system can be used on rigid and articulated vehicles, as well as for off-motorway vehicles. It is intended to monitor the lateral (driver and passenger side) blind spots, and detects both stationary and moving objects, including VRUs.

Implementation

The system uses dual radar sensors which have a protection rating IP69K. The sensors operate on 12V, with a current consumption of 0.36A. The sensors have a range of 70m (±0.3m). The FoV is not specified.
The HMI warns the driver by means of visual and auditory signals. The nature of these signals is not specified in the manual, but a photograph on the website suggests that visual warnings are provided by LED lights mounted in the vehicle A-pillars.
The system is stand-alone. Power can be provided by battery and data are transmitted between the radar sensors and the ECU wirelessly, over a maximum distance of 20m.

Scientific Validity

Data on scientific validity are not available.

Unit Cost

Unit cost for a system falls in the €€ category. This price is not related to a MOQ.

Availability

Data on system availability are not available.

E.18 KudaUK

The company did not respond to contact requests. The following information was extracted from a description on the product website.

E.18.1 SideWarn

Operational Design Domain

The SideWarn system is marketed as a cyclist and pedestrian blind spot detection system on the co-driver's side for rigid and articulated vehicles (categories N2, N3, M2, M3) as well as construction vehicles. The system is intended for turning manoeuvres up to a speed of 26km/h and it is available as a retrofit kit.

Implementation

Four ultrasonic sensors with an IP66 protection rating are used on the side of the cabin and just behind the front wheel. According to the product website, the system warns of objects using a warning light and audio signal within 0.5m of the vehicle. Whether this is the maximum range of the sensors could not be derived. The system is compliant with FORS, Crossrail and Transport for London regulations. In terms of maintenance, the company recommends checking the system on a regular basis, as part of a daily walk-around check.

Scientific Validity

Data on scientific validity are not available.

Unit Cost

The unit cost of one system is in the € category.

Availability

Data on system availability are not available. KudaUK offers fitting services in the United Kingdom.

E.19 MAN

MAN offers several systems as part of their truck catalogue (N2 and N3 vehicle categories). The company did not respond to contact requests. The following information was extracted from descriptions on the product website.

E.19.1 Side camera system

Operational Design Domain

The MAN Side camera system is designed to warn truck drivers about the presence of other road users when turning, manoeuvring, and changing lanes. The system works on both rigid trucks and articulated trucks. The system is available as retrofit, but it is not possible to infer whether retrofit kits are available for MAN trucks only, or also for trucks manufactured by other companies. Imagery on the product website displays a cyclist in the area captured by a sensor, which presumably corresponds with the 150 degrees field of view of a video camera. It is not possible to infer whether the ultrasonic sensors, which are used for object detection, are designed to detect bicyclists or pedestrians.

Implementation
The MAN Side camera system makes use of two sensor types. First, a 150 degrees field of view camera mounted on the side of the cabin is connected to a display inside the cabin to provide a continuous view for the driver. Object detection is enabled through ultrasonic sensors. According to the product website, if another road user approaches the vehicle, an optical signal will inform the driver. An additional acoustic signal sounds if an obstacle is within the hazard zone when the driver is getting ready to drive off. Specifications of the hazard zone size are not available.

Scientific Validity
Data on scientific validity are not available.

Unit Cost
Data on unit cost are not available.

Availability
Data on system availability are not available.

E.19.2 Turn assist

Operational Design Domain
MAN's turn assist is designed to warn drivers when making a turn, e.g., at intersections where other road users may be present next to the cabin on the co-driver's side. Based on imagery on the product website, the system can be implemented on rigid as well as articulated trucks. Furthermore, the product website suggests that the turn assist system is able to detect pedestrians and bicyclists. The system does not appear to be available as retrofit option.

Implementation
Two radar sensors (total FoV ~180°) are used to detect other road users on the co-driver's side when the driving speed is below 30 km/h. A three-staged warning is used to warn the driver of the presence of other road users. According to the product website, the first stage involves one of the three LEDs on the A-pillar lighting up if a moving object is detected in the warning area while the indicator is on and the wheels are turned into a large angle. The second stage is intended to warn the driver of a likely collision, resulting in all three LEDs lighting up. Finally, the LEDs flash in the third stage to signal that immediate driver intervention is required to prevent a collision. No information is provided on the methods used to discern between the three stages.

Scientific Validity
Data on scientific validity are not available.

Unit Cost
Data on unit cost are not available.

Availability
Data on system availability are not available.

E.19.3 Lane change support (LCS)

Operational Design Domain
MAN's LCS is designed to warn drivers about road user presence before changing lanes. Based on imagery on the product website, the system can be implemented on rigid as well as articulated trucks. The product website does not indicate whether the system is able to detect and warn for

pedestrians and cyclists. However, seeing that the system functions only with a driving speed of at least 50 km/h, the system does not seem to be designed for VRU detection (for VRUs one may need to use the 'Turn assist' system described above). The system does not appear to be available as retrofit option.

Implementation
Two radar sensors are used; one for each side of the vehicle. The size of the warning zone is variable from 0 m to a maximum of 8 m to the front of the vehicle, and 80 m to the rear (from the vehicle front). A two-staged warning is used. An LED is illuminated when a road user is detected in the warning zone. If in addition the driver uses the turn indicator or initiates a lane change, three LEDs light up.

Scientific Validity
Data on scientific validity are not available.

Unit Cost
Data on unit cost are not available.

Availability
Data on system availability are not available.

E.19.4 Lane change collision avoidance assist

Operational Design Domain
MAN's lane change collision avoidance assist appears to have the same operational design domain as the LCS system described above, with the addition that the system is able to intervene by applying a steering torque in case of an imminent collision with another road user. The system does not appear to be available as retrofit option.

Implementation
As with the LCS system, two radar sensors are used, spanning an identical warning zone. Contrary to the LCS system, a three-staged warning is used. The first two stages are identical to the LCS system: a single LED is lit when a road user is detected in the warning zone (stage 1) and three LEDs are lit when in addition a lane change is initiated by steering or by activating the indicator (stage 2). If the steering movement is continued, the three LEDs flash, an acoustic signal sounds, and the vehicle actively steers back into its own lane.

Scientific Validity
Data on scientific validity are not available.

Unit Cost
Data on unit cost are not available.

Availability
Data on system availability are not available.

E.20 Mercedes-Benz

The company did not respond to contact requests. The following information was extracted from a description on the product website, which includes a brochure on safety systems.

E.20.1 Sideguard Assist

Operational Design Domain

The Sideguard Assist system is situated on the co-driver's side of the vehicle and assists the driver when turning, manoeuvring, and changing lanes. The system is capable of detecting (imminent collisions with) moving and stationary objects, including VRUs, traffic lights and lampposts. The system can be used on rigid and articulated trucks manufactured by Mercedes-Benz, as part of new trucks and as retrofit on older models.

Implementation

An array of two radar sensors covers a detection zone of 21.75m alongside the vehicle by 3m from the side of the vehicle. A staged warning is implemented. An orange LED is illuminated in case an object is detected. A flashing red LED is shown in combination with a warning tone through the vehicle's built-in speakers in case of 'danger of collision' (presumably derived from object presence in combination with steering wheel angle and/or trailer articulation angle).

Scientific Validity

Numerical data on scientific validity is not available. Mercedes-Benz does state that certain environmental situations are unfavourable for detecting objects (e.g., obstacles concealed by fences or similar, or very poorly reflecting objects with a low reflection cross-section).

Unit Cost

Data on unit cost are not available.

Availability

Data on system availability are not available.

E.21 MobilEye

MobilEye responded to our inquiries and provided additional information on their systems.

E.21.1 FishEye

Operational Design Domain

The MobilEye FishEye system is a solution available both as an OEM and as a retrofit option. It is suitable for rigid and articulated vehicles, and can detect stationary and moving VRUs. It is compliant with UNECE Regulations 151 and 159.

Implementation

The system makes use of between two and four cameras. The system operates at voltages of 12/24V and consumes 6W of power.
Each camera has a FoV of 150° horizontally, by 117° vertically, and an effective range of 35-40m.
The HMI consists of dual display units, mounted on the vehicle A-pillars. The display units feature lights in the shape of a pedestrian. A yellow LED lights up when a VRU is detected, and a red LED lights up when a collision is imminent. In the latter case an auditory alarm sounds as well.
The system connects to the vehicle over CAN bus and requires information on vehicle speed and TSI. Optional are brake, wiper, reverse, and high-beam signals.

Scientific Validity

System performance has been evaluated according to test protocols required for UNECE R151 (14 experimental trials) and UNECE R159 (6 experimental trials) certification.

Unit Cost

Pricing is dependent on the number of cameras, but in the €€€ category.

Availability

There are no restrictions on availability worldwide. Systems can be delivered at a specified rate and lead time.

E.22 oToBrite

oToBrite responded to our inquiries and provided additional information on their systems.

E.22.1 oToBrite BSIS

Operational Design Domain

The oToBrite BSIS (Blind Spot Information System) is a stand-alone system designed for rigid commercial vehicles of UNECE categories M2, M3, N2, and N3, and is designed to meet UN Regulation No. 151 (Uniform provisions concerning the approval of motor vehicles with regard to the Blind Spot Information System for the Detection of Bicycles) requirements. It is intended for detection of pedestrians and cyclists moving at speeds between 1-20km/h when drivers perform right turns. In communication, oToBrite indicated that the system will also detect stationary objects and is not necessarily limited to turning manoeuvres.

Implementation

The system uses a dual camera with a forward and backward view. The camera unit has an IP protection rating IP67/69K and the ECU a waterproof rating IP52. Operating voltage is between 9-32V, and power consumption is 8W.
The area monitored by the camera is 43m wide and 4.75m deep; extending 9m to the front of the vehicle and 34m towards the back, relative to the camera mounting position.
The system features an indicator display with a yellow and a red LED. Staged warnings are given at two levels: a level 1 warning consists of the yellow LED lighting up when a VRU is present in the monitored area; a level 2 warning consists of the red LED lighting up when a VRU is present in an area 8m wide (extending 2m to the front of the camera) and 1m deep, in closest proximity to the sensor mounting location.
The system integrates with the vehicle, and requires a speed signal and connection to the turn signal indicators. The type of connection has not been specified.
The system is stated to be compliant with reliability standards ISO 16750-4/IEC 6006-2, and ElectroMagnetic Compatibility (EMC) standards ISO 16750-2/ISO 10605/VSCC 56-1.

Scientific Validity

According to the product manual, the detection sensitivity is 95% for level 1 warnings and 99% for level 2 warnings. No further information on the testing protocol was available.

Unit Cost

Quotes for unit costs were obtained for all the provided business cases. Each case had a € category pricing.

Availability

Systems are available globally, and a specified number of systems can be supplied. The rate at which the systems can be supplied was not specified.

E.22.2 oToGuard

Operational Design Domain

The oToGuard system is a multi-camera system which monitors the entire surround of the vehicle and detects the presence of VRUs. In communication, it was indicated that the system also detects stationary objects. It is compatible with rigid heavy commercial vehicles and buses of classes M2, M3, N2, and N3. It is claimed to have a wide range of functionalities and to be compliant with a considerable range of UNECE regulations: R130 on Lane Departure Warnings, R131 on Forward Collision Warnings, R151 on Blind Spot Information Systems, R158 on Reversing Information Systems, and R159 on Moving-Off Information Systems. The system also features a camera monitoring the driver and is said to detect various driver states. As such, it is theoretically suitable for a wide range of functionalities that extend beyond blind spot monitoring, but also support Advanced Driver Assistance Systems up to at least SAE level 2[6].

Implementation

The system features 8 cameras, with protection ratings IP67/69K and an ECU with protection rating IP52. The operating voltage ranges between 9-32V, and it consumes 15W of power. The cameras have various FoV: camera 1 and 2 face forward, with respective FoV of 63.8° and 137°; camera 3 and 4 face the passenger side of the vehicle with FoV of 137° and 100°, which partially overlap; cameras 5 and 6 are the same as camera 3 and 4, but monitor the driver side of the vehicle; camera 7 monitors the rear of the vehicle and has an FoV of 137°. Camera 8 has an FoV of 61°. It is mounted inside the cabin and monitors the driver.
The system generates visual-auditory warnings with 2 stages. Although not explicitly stated, it presumably functions as in the oToBrite BSIS system, where a level 1 warning consists of a yellow LED lighting up when a VRU is present in the monitored area; and where a level 2 warning consists of a red LED lighting up and an auditory alarm when a VRU is present in a near-range area.
The system connects to the vehicle over CAN, and makes use of Ethernet, GPIO and USB connections. It requires as input data vehicle forward velocity, turn signal indicator and a gear indicator.
The system is stated to be compliant with reliability standards ISO 16750-4/IEC 6006-2, and ElectroMagnetic Compatibility (EMC) standards ISO 16750-2/ISO 10605/VSCC 56-1.

Scientific Validity

Data on scientific validity are not available.

Unit Cost

Quotes for unit costs were obtained for all provided business cases. Each case had a €€€ category cost.

Availability

Systems are available globally, and a specified number of systems could be supplied within a specified timeframe.

6. SAE (Society of Automotive Engineers) automation levels are a taxonomy consisting of six levels of driving automation. Level zero refers to no automation; level five represents autonomous vehicles; other levels have intermediate, incremental automation functionality. Level two features lane-keeping functionality and adaptive cruise control (https://www.sae.org/blog/sae-j3016-update).

E.23 Rear View Safety

Rear View Safety did not respond to contact requests. The following information was extracted from descriptions on the respective product websites.

E.23.1 Waterproof Backup Sensor Reversing System

Operational Design Domain

The Waterproof Backup Sensor Reversing System is intended for rigid vehicles ranging from pickup trucks to heavy trucks. It monitors for the presence of stationary and moving objects, including vulnerable road users in the blind spot behind the vehicle, when the reverse gear is engaged.

Implementation

The system consists of four ultrasonic sensors which are to be mounted in the vehicle rear bumper. As suggested by the system name, the components are waterproof. Sensors have an IP68 rating. For the ECU a protection rating IP65 is indicated.
The system operates for voltages between 10-28V, where 12V is stated as nominal value. Current consumption is 0.06A for each of the sensors and the ECU alike; totalling 0.3A.
Individual sensors have a horizontal FoV or 51° by 62° vertically. The range of individual sensors is approximately 0.6m wide by 1.4m deep. The array of sensors could therefore cover a maximum width of 2.4m.
The HMI warns the driver of the presence of objects by audio pulses. The frequency and intensity of pulses increases with obstruction proximity. When an object moves through the system FoV, a separate loud auditory warning is given.
The system requires a connection to vehicle power and ground, as well as a reverse trigger.
The system is compliant with standards TS 16946:2009; ISO 9001:2008.

Scientific Validity

Data on scientific validity are not available.

Unit Cost

Unit cost is in the € category. The price is not related to an MOQ.

Availability

Data on system availability are not available.

E.23.2 Sensestat Wireless Obstacle Detection Sensor System

Operational Design Domain

The Sensestat Wireless Obstacle Detection Sensor System appears to be an extension of the Waterproof Backup Sensor Reversing System. Similarly, it is intended for rigid vehicles ranging from pickup trucks to heavy trucks. It makes use of a similar, and possibly the same, sensor array. It is different in that it features a wireless connection between sensors and ECU, which also allows connection of a given tractor with different trailers equipped with a sensor array. In addition, it features a display unit. It monitors for the presence of stationary and moving objects, including vulnerable road users in the blind spot behind the vehicle, when the reverse gear is engaged.

Implementation

The system consists of four ultrasonic sensors which are to be mounted in the vehicle rear bumper.

The system operates for voltages between 10.5-24V. Current consumption by the ECU and display together is 0.45A. Assuming that the same sensors are used as in the previous system, this amounts to a total of 0.85A.
The FoV of individual sensors is not exactly specified. The range of each sensor is approximately 0.6m wide by 1.4m deep. The array of sensors could therefore cover a maximum width of 2.4m.
The HMI warns the driver of the presence of objects by means of a visual display and buzzer. The display shows a stack of 7 LED segments ranging in colour from yellow to red for each sensor. Segments light up depending on proximity of obstructions. The system also provides auditory warnings in the form of pulses, with a frequency that increases with obstruction proximity. The warning stages start at a range of 1.7m, and intervals between subsequent stages gradually decrease from 0.7m to approximately 0.1m.
The system requires a connection to vehicle power and ground, as well as a reverse trigger.
The system is compliant with standards TS 16946:2009; ISO 9001:2008. The sensors can connect to the ECU wirelessly. Wireless operation allows the use of a given tractor with different trailers equipped with a sensor array via a 'sync' button.

Scientific Validity
Data on scientific validity are not available.

Unit Cost
Unit cost is €. The price is not related to an MOQ.

Availability
Data on system availability are not available.

E.23.3 Advanced Blind Spot Sensor System

Operational Design Domain
The Advanced Blind Spot Sensor system is suitable for rigid commercial vehicles. It monitors the blind spots on the driver side as well as the passenger side, and is suitable for detection of moving objects, including VRUs.

Implementation
The system makes use of dual radar sensors with an IP67 protection rating. Operating voltage is between 9-32V; current consumption is 0.2A.
Each sensor has a circular FoV with a 40° diameter. The sensor detects objects up to 25m towards the rear of the vehicle. The minimum object resolution is not exactly specified. Instead, the manual states cars are detected up to 15.2m; motorcycles up to 10.1m; and pedestrians up to 7m.
The HMI warns the driver of objects present in the blind spots by means of LED mounted in the vehicle A-pillars and by auditory signals emitted by a buzzer. Details on the nature of the warnings are not given in the manual.
The system requires a power and ground connection, along with connections to the left and right turn signals, and optionally to a reverse signal.
The system is compliant with standards SAE J1455; ISO 17387:2008; TS 16946:2009; ISO 9001:2008.

Scientific Validity
Data on scientific validity are not available.

Unit Cost
Unit cost is €€. This price is not related to an MOQ.

Availability

Data on system availability are not available.

E.24 Roadefend Vision Technologies

Two blind spot detection systems by Roadefend Vision Technologies were found, and for both of these systems information was provided by the company. The difference between these systems is mainly in the ECUs; peripherals such as cameras and displays appear to be interchangeable.

E.24.1 Smart Video Monitoring and Alarm System AI-5-E

Operational Design Domain

The AI-5-E ECU combined with a dedicated camera and a display (hereafter: system) is able to generate rear and side blind spot warnings when other road users (including VRUs) are in the detection zone. The system can be retrofitted to rigid and articulated trucks (N2, N3).
The system is modular: combined with other (video-based) sensors, the system can additionally serve as driver state monitoring system (e.g., fatigue detection), ADAS system (e.g., forward collision warnings, lane departure warnings) and driving behaviour (e.g., harsh braking, harsh cornering).

Implementation

The AI-5-E (protection rating: IP43) uses artificial intelligence image processing algorithms to detect road users via one or at most two blind spot detection cameras (protection rating: IP68). The cameras have a horizontal FoV of 85° and a vertical FoV of 50°. No specifications on the size of the detection zone were supplied. Warnings are provided on an LED display, but no information was provided on the characteristics of these warnings.
The system draws its power from the vehicle battery (operating voltage range: 8-32V). Each camera draws a current of 50-200mA (AI-5-E current consumption not supplied). The system makes use of CAN signals (e.g., high beam, turn left, speed, reverse, front door, break, turn right). Finally, the system is flame-retardant (compliant with UL94) and shock-resistant (compliant with MIL-STD-810H 2019). The AI-5-E ECU is not compliant with the RoHS directive, which means the system may not be sold in Europe.

Scientific Validity

According to Roadefend Vision Technologies, the sensitivity of the system is >95%. No information was provided on how this figure was obtained. When asked about false alarm rates, Roadefend Vision Technologies answered that there are no precise data.

Unit Cost

A system consisting of the AI-5-E, two blind spot cameras, one normal camera, one LED display, and extension cables has a € unit cost.

Availability

Data on system availability were not made available. Given the non-compliance with the RoHS directive, the system may not be available in Europe.

E.24.2 Full HD Vehicle Intelligent Analysis System AI-8-BOXHP

A system based on the AI-8-BOXHP is largely identical to a system based on the AI-5-E described above. Only differences are reported here.

Operational Design Domain

Identical to the AI-5-E system.

Implementation
The AI-8-BOXHP has an IP66 protection rating and operates with a voltage range of 9-36V. The system is compliant with the RoHS directive.

Scientific Validity
Identical to the AI-5-E system.

Unit Cost
A system consisting of the AI-8-BOXHP, two blind spot cameras, one normal camera, one LED display, and extension cables has a €€ unit cost.

Availability
Data on system availability were not made available, but given that the system is compliant with the RoHS directive, the system is probably available in Europe.

E.25 Rosco Vision

Rosco Vision did not respond to contact requests. The following information was extracted from a description on the product website.

E.25.1 BSSK4000 Vehicle Rear Object Detection System

Operational Design Domain
The system is intended for use with rigid trucks. It is suitable for the detection of obstructions (not further specified) during reversing manoeuvres.

Implementation
The system makes use of 6 ultrasonic sensors, four of which are to be mounted at the vehicle rear bumper and two at the top of the box. The sensors have protection rating IP67; the ECU has a protection rating IP65.
Power must be provided by the vehicle. The operating voltage ranges between 10.5-32V, and current consumption is 0.3A.
The six sensors are of three types: sensors 1 and 2, mounted on the driver side of the bumper have a range of 1.82m with an accuracy of 0.15m; sensors 3 and 4, mounted on the passenger side of the vehicle have a range of 3.96m with an accuracy of 0.03m; and the two sensors mounted on the top of the vehicle have a range of 1.22m with an accuracy of 0.15m. The sensor FoV is not specified.
The minimal object resolution is approximately 0.37°.
The HMI consisting of display and buzzer warns the driver by means of multiple levels of proximity warnings. The display shows 6 bars for sensors 1-4 each, ranging from green via yellow to red, corresponding to increasing object proximity. Beeps increase in frequency with proximity of the closest obstruction.

Scientific Validity
The manual states that sensor sensitivity can be adjusted. No other data on scientific validity are available.

Unit Cost
The unit price of a complete system is €.

Availability
Data on system availability are not available.

E.26 Rostra Accessories

Three blind spot monitoring systems by Rostra Accessories were identified. The company provided information on one of these systems. For the other systems, the following information was extracted from a description on the product website.

E.26.1 Blind Spot Detection System 250-1930

Operational Design Domain

The system can be used on the side and rear of a vehicle to support lane changes (when driving above 24km/h) and reversing, respectively. In case of reversing, the system warns for rear cross traffic. Moving objects are detected, including VRUs. The system is available as retrofit kit for rigid and articulated vehicles.

Implementation

The system makes use of 2 radar sensors (one on each side of the vehicle) with an IP69K protection rating, connected to an ECU (IP40 protection rating). The sensors have a ±35° horizontal FoV and a ±15° vertical FoV, with an accuracy of ±1.5° and a precision of 3°. Each sensor covers a detection area of up to 4.5m by 15m, with an accuracy of ±0.4m and a precision of 0.8m. LED indicators are illuminated when an obstacle enters the detection area. If the turn signal is on while an object is detected, the LED indicators flash and a buzzer 'beep' is played. The system includes a malfunction indicator (unspecified). Apart from power supply through the vehicle's battery (9-12V, <0.5A at 12V), the system requires turn signal and reverse gear information. For proper functioning, the sensor surface must be cleaned when it is soiled.

Scientific Validity

According to Rostra Accessories, the proportion of true positives is at least 99.8%, and the proportion of false positives is smaller than 0.1%. These figures were obtained through 10,000 observations by testing on a "variety of comprehensive road conditions" as well as temperatures (range unspecified) at a resolution of 0.5m. When asked if usability tests were performed, Rostra Accessories noted that mass installation tests on real vehicles were performed. If and how driver experience was measured and used was not part of the supplied information.

Unit Cost

Data on unit cost are not available.

Availability

Data on system availability are not available.

E.26.2 RearSentry Fleet Vehicle Object Detection

Operational Design Domain

The system is mounted at the rear of a vehicle and intended for assisting drivers when reversing. The retrofit kit is available for rigid vehicles (N2, N3). The product website did not state whether the system can also be used on articulated vehicles, nor whether VRUs are detected.

Implementation

A radar sensor with a range of 3.7m is used to detect objects. Object distance is converted to a tri-colour warning scheme (distance thresholds not specified): green (alert), orange (hazard), and red (danger). An audible alert is presented as well, but no details are provided if and how its presentation is related to object distance.

Scientific Validity
Data on scientific validity are not available. Rostra Accessories claims that the system is not affected by adverse weather conditions such as extreme heat or cold, rain, sleet, snow, hail, mist or fog (note: this may be a common feature for radar sensors).

Unit Cost
Data on unit cost are not available.

Availability
Data on system availability are not available.

E.26.3 Student Detection System

Operational Design Domain
The system is designed to inform bus drivers of obstacles around their vehicle, including VRUs (e.g., students, children). Based on the product website, the system appears to assist drivers when reversing, and probably also when turning, moving off, and changing lanes. Whether the system is available as retrofit kit or as OEM solution could not be inferred.

Implementation
A total of 10 radar sensors are mounted at various locations (front, side, rear) of the vehicle. Connected to a dedicated display, each location turns from green to flashing red when an object is detected, combined with an auditory alert. The system automatically clears if no new intrusions are detected within 4 seconds of the last intrusion.
The system makes use of a reverse gear signal for warnings relating to the rear of the vehicle. Rostra Accessories claims that the system works in all weather conditions with no external cleaning.

Scientific Validity
Data on scientific validity are not available.

Unit Cost
Data on unit cost are not available.

Availability
Data on system availability are not available.

E.27 Sensata Technologies

Three blind spot detection systems by Sensata Technologies were identified. The company provided manuals and data sheets. Furthermore, information was extracted from a description on the product website.

E.27.1 PreView Side Defender II

Operational Design Domain
The Preview Side Defender II system is designed to warn drivers about other road user presence when turning (including VRUs, with a driving speed up to 30km/h) and changing lanes. The system focuses on moving objects and ignores stationary objects. The system is available as retrofit kit and as OEM solution.

Implementation

Object detection is performed using an IP69K rated radar sensor with a 150° horizontal FoV and a 20° vertical FoV. The accuracy decreases at larger angles and is specified at ±2° at ±10° FoV, ±5° at ±30° FoV, and ±10° at ±75° FoV. The radar sensor covers a detection area of up to 12m alongside the vehicle by 0.6m to 3m next to the vehicle, with a detection accuracy of 0.3m. Static objects must be at least 1.4m to be detected (and presumably filtered), whereas the minimum detection size for dynamic objects is 0.3m.

The system can warn drivers with audible and visual alerts through a dedicated LED armature, or by using an optional PreView Plus display (in which case cameras can also be connected for a real-time view on blind spots). LEDs are illuminated when an object is detected. LED colours change with object distance. An audible alert is provided if the turn signal is active. The system can detect multiple road users in the detection area. With driving speeds up to 30km/h, priority is given to alerting for cyclists. When the driving speed is above 30km/h, priority is given to moving vehicles in adjacent lanes.

The system draws power from the vehicle's battery, with an operating voltage of 9-33V and a current consumption <0.5A. For retrofit applications, the system's display can provide a GPS based vehicle speed message, while OEM and coach builders can connect the display directly to the vehicle J1939 CAN bus for vehicle speed information.

No expected lifetime of the system is provided. The warranty of the sensor extends for 60 months from the date of shipment. The system has a continuous self-test which notifies the driver of system failures via the in-cab display. Sensata Technologies recommends that the equipment operator check for proper operation at the beginning of every shift or safety inspection period.

Scientific Validity

A test report of TÜV Süd was shared, showing that the system meets the requirements for national type approval of a BSIS for the detection of bicycles.

Unit Cost

No pricing for OEMSs could be given, because these are protected by OEM contracts. Quotes for unit costs of retrofit kits were obtained for the provided business cases:

(1) 1,000 12m rigid trucks: €€€

(2) 10,000 16.5m tractor/trailer combinations: €€

Availability

The system is available globally, except for countries under restrictions. The system can be supplied in a specified timeframe, with a known production capacity.

E.27.2 PreView Sentry

Operational Design Domain

The PreView Sentry is a modular radar system that can be used for monitoring the rear, front, and sides of a vehicle. The system can be applied to rigid and articulated vehicles (categories N2, N3, M2, M3) as well as construction and mining vehicles. It can detect stationary and moving objects, including VRUs. Depending on its location on the vehicle and subsequent configuration, the system can be used as BSIS, MOIS, or REIS. This means that in theory, the system assists with turning, moving-off and reversing manoeuvres. However, the supplied manuals only include examples for reversing. The system is available as retrofit kit and as OEM solution.

Implementation

Object detection is performed using an IP69K rated radar sensor with the same FoV specifications as the PreView Side Defender II sensor: a 150° horizontal FoV and a 20° vertical FoV, with accuracy decreasing at larger angles: ±2° at ±10° FoV, ±5° at ±30° FoV, and ±10° at ±75° FoV. The detection area is larger, configurable, and spans an area of up to 8m wide by 30m deep, with a

detection accuracy of 0.3m. Static objects must be at least 1.4m to be detected, whereas the minimum detection size for dynamic objects is 0.3m.
The system can warn drivers with audible and visual alerts through a dedicated LED armature, or by using an optional PreView Plus display (in which case cameras can also be connected for a real-time view on blind spots). The detection area is divided into 5 zones. LEDs are illuminated when an object is detected, the colour of which depends on the detection zone in which an object is detected (green, green, yellow, orange, red). In addition, a 'beep' is generated, the repetition rate of which increases as objects draw nearer.
The system draws power from the vehicle's battery, with an operating voltage of 9-33V and a current consumption <0.25A. The reverse gear signal is obtained through the J1939 CAN bus. The system is compliant with the J1455 standard. No expected lifetime of the system is provided. The warranty of the sensor extends for 60 months from the date of shipment. The system has a continuous self-test which notifies the driver of system failures via the in-cab display, including blockage of the sensor with excessive ice, mud, or snow. Sensata Technologies recommends that the equipment operator check for proper operation at the beginning of every shift or safety inspection period.

Scientific Validity

Data on scientific validity are not available. A Youtube video on the product website shows a calibration procedure in which cones are placed to check if a pedestrian is detected behind the vehicle.

Unit Cost

No pricing for OEMSs could be given, because these are protected by OEM contracts. The following quotes for unit costs of retrofit kits were obtained for the provided business cases:
(1) 1,000 12m rigid trucks: €€€
(2) 10,000 16.5m tractor/trailer combinations: €€
(3) 1,000 cranes: USD 1390 €€

Availability

The system is available globally, except for countries under restrictions. The system can be supplied in a specified timeframe, with a known production capacity.

E.27.3 PreView SentryX

The PreView SentryX appears to be identical to the PreView Sentry system, except that the radar sensor features a bell-shaped detection curve intended for inset mounting at the back of large haul mining vehicles. Consequently, the horizontal FoV is 70° up to a depth of 1m (to avoid continuous detection due to its inset mounting) and a horizontal FoV of 120° from a depth of 1m to 30m.

E.28 Stoneridge-Orlaco

Stoneridge-Orlaco produces two blind spot monitoring systems within the scope of our inventory: SideEye and RadarEye. Information on the SideEye system was supplied by Stoneridge-Orlaco. Information on the RadarEye system was retrieved from the product website, including a demonstration video and an information leaflet.

E.28.1 SideEye

Operational Design Domain

SideEye classifies as a BSIS. It assists drivers in monitoring the co-driver's side of their vehicle when making a turn at driving speeds up to 30 km/h. The system is able to distinguish between moving objects and static objects and can detect VRUs. It can be implemented on rigid as well as articulated vehicles (N2, N3, M2, M3 vehicle categories), as well as on construction / mining vehicles (possibly by using an additional mounting bracket). The SideEye system is available as retrofit kit. In new generation DAF trucks, the system can be delivered as a vehicle component.

Implementation

SideEye combines a single radar sensor (for object detection) with a single camera sensor (for real-time visual display). The radar sensor (protection rating: IP69K) has a maximum coverage of 12m (width, alongside the vehicle) by 3m (depth). The sensor does not detect objects within 0.6m depth, meaning that the effective depth of the warning zone is 2.4m. The manual states that the detection zone is approximate and varies depending on the detected object and operating conditions. No specifications are provided on the minimum size for an object to be detected and at which distance such detection takes place.

The radar sensor and the camera sensor (horizontal FoV: 118°, vertical FoV: 78°) are both connected to an interface box mounted inside the cabin (protection rating: IP30). The interface box can be connected to an external LED display (protection rating: IP67), or to the vehicle's internal display (if present). Either display is used to provide a real-time view of the side of the vehicle. Detected objects are highlighted on the display with a coloured box and accompanied by an auditory alert. As detected objects get closer to the vehicle, the highlight colour changes from green to red, and the auditory alert increases in pitch as well as repetition rate (akin to typical parking sensors).

The system is powered by the vehicle's power supply, operating with a voltage between 12V and 60V (display: 12-24V). Besides power supply, the system requires reverse, tachograph and turn signals from the vehicle. Stoneridge-Orlaco claim an expected lifetime of 7 years (2 years warranty, expandable to 7 years). Regarding maintenance, the product manual states that *"A walk around test shall be performed every day to verify proper function of the system and to familiarize the operator with the zone of detection."*

The systems comply with the Direct Vision Standard as well as a TÜV Süd assessment for the category 'blind spot information systems for the detection of bicycles'.

Note: according to the test report of TÜV Süd the radar sensor of the SIdeEye system concerns a PreView SideDefender module manufactured by PRECO (nowadays Sensata Technologies, see 3.27). Seeing that the interface box, camera, and monitor are manufactured by Stoneridge-Orlaco, the SideEye system is viewed as an original system in the present inventory.

Scientific Validity

The TÜV Süd test report states that SideEye meets the requirements for a true-positive test (e.g., correctly detecting an object when it is within the specified detection zone). Furthermore, SideEye meets the requirements for a false-positive test conducted with, amongst others, traffic signs at various heights.

Unit Cost

The following quote for unit cost was obtained for each of the provided business cases: €€€ per complete set, part number 0403130 (monitor with bracket, wires, interface box, SRD sensor and camera).

Availability

Stoneridge-Orlaco states that SideEye can be delivered immediately without regional restrictions, depending on the quantity.

E.28.2 RadarEye

Operational Design Domain

The RadarEye system can be used universally around the vehicle (e.g., front, side, rear) on rigid vehicles, articulated vehicles, as well as other large vehicles (e.g., construction vehicles, forklift trucks, cranes). The manual provides examples for detection of moving objects (including VRUs) for turning and reversing manoeuvres.

Implementation

An interface box serves as hub for one or more radar sensors (protection rating unspecified), compact cameras (protection rating: IP69K) and an LED display (protection rating unspecified). The radar sensors have a horizontal FoV of 70°, a vertical FoV of 11°, and cover a maximum width of 4m and a maximum depth of 20m. For front and rear object detection two radar sensors are used in an array to cover a larger horizontal FoV. The detection area is configurable in terms of shape (rectangular, circular) and in terms of range (2-20m) to avoid unnecessary alarms. The range is divided in five equidistant detection zones, which are used to provide staged warnings. Detected objects are highlighted on the display with a coloured box and accompanied by an auditory alert. As detected objects get closer to the vehicle, the highlight colour changes from green to red, and the auditory alert increases in pitch as well as repetition rate.

Scientific Validity

Data on scientific validity are not available.

Unit Cost

Data on unit cost are not available.

Availability

Data on system availability are not available.

E.29 Tenet

Tenet responded to contact requests and provided information for their systems.

E.29.1 DVS Camera with Blind Spot Information System

The system offered by Tenet is modular, and can combine up to 16 proximity sensors and one to four cameras. Four typical combinations are on offer, and quotes for these combinations have been obtained. Given that these systems only differ in the number of sensors, they are not described separately.

Operational Design Domain

No specific information on the subcategories of the Operational Design Domain was available. Example applications in photographs indicate that the systems can be used with rigid trucks and buses, as well as off-motorway vehicles (i.e., an excavator).

Implementation

Typical applications consist of four proximity sensors per side of the vehicle, a camera, ECU and monitor. All available combinations include the camera, ECU and monitor, but vary in which sides of the vehicle are covered by proximity sensors. The possibilities are rear-view only; rear and front-view; rear, left *or* right, and front-view; and rear, left, right and front view. These variations are names BLIS-B4, BLIS-B4F4, BLIS-B4F4L4/BLIS-B4F4R4, and BLIS-360.
The proximity sensor types are not specified. However, based on appearance and specifications, they are most likely ultrasonic sensors.

Operating voltage is specified as 12-36V, and current consumption is 0.5A. As an array of 16 sensors placed around the vehicle, the horizontal FoV covers 360°, and has a depth of 5m. It is not exactly specified how the system warns the driver or intervenes when an object is detected. Depictions of the system nevertheless show that the monitor features a top-down view of the vehicle with visual representations of three proximal zones per sensor, with colours changing from green via yellow to red, for more proximal zones. This suggests that these areas light up when an object is detected by the corresponding sensor, at the corresponding proximity. The system uses CAN, LIN and UART connections. It requires as input information on the left and right TSI, engagement of reverse gear and GPS.

Scientific Validity
Data on scientific validity are not available.

Unit Cost
Prices for BLIS-B4, BLIS-B4F4, BLIS-B4F4L4/BLIS-B4F4R4, and BLIS-360 are all in the € category. Sample kits are available with a small discount.

Availability
Data on system availability are not available.

E.30 The Vehicle Group (TVG)

The company did not respond to contact requests. As a result, it was not possible to determine whether TVG is the original manufacturer of the SideSafe system described below. The following information was extracted from a description on the product website, as well as a study by Frampton and Millington (2022).

E.30.1 SideSafe

Operational Design Domain
The SideSafe system is designed to warn HGV drivers of objects (including VRUs) on the co-driver's side when making a turn. The system is available as retrofit kit.

Implementation
SideSafe makes use of an array of four ultrasonic sensors for object detection and a single camera to provide a real-time view of the side of the vehicle. Power is obtained from the vehicle (operating voltage not specified). Coloured LEDs and an auditory signal are used to warn the driver. There are three warnings stages based on proximity. The recommended action for objects between 0.6m and 0.8m (stage 1) is to proceed with caution. Green LEDs are illuminated at this stage. The LED colour turns to orange when objects are detected between 0.4m and 0.6m (stage 2), with a recommended action to slow down the vehicle. For objects between 0m and 0.4m, the vehicle is recommended to stop. The LEDs is now red and a continuous audio alert is provided.

Scientific Validity
A pedestrian surrogate target with a height of 1267mm (i.e., the 5th percentile of an Italian female) was used to test the performance of the ultrasonic sensors of the SideSafe system. The test was performed on a bright sunny day, with an average daytime temperature and little wind. For performance on the side of the vehicle, the target was placed on any of 186 nodes on a test grid of 6m by 1m with a spatial resolution of 0.2m. Frampton and Millington (2022) demonstrate that the sensor system missed 52% of the expected detection nodes (e.g., 56% of "stop vehicle" nodes, 45% of "slow down" nodes and 48% of "proceed with caution" nodes).

For performance on the front corner of the vehicle, the target was placed on any of 66 nodes on a 2m by 1m test grid, again with a spatial resolution of 0.2m. Here, the sensor system missed 70% of the ideal detection nodes (68% of "stop vehicle" nodes, 73% of slow down" nodes and 73% of "proceed with caution" nodes).
In terms of false alarms, the sensor array on the side of the vehicle showed one node with a detection ('proceed with caution') where no warning was supposed to be triggered, corresponding with a specificity of 99.5%. For other detection nodes the specificity was 100%.
It may be noted that due to the study of Frampton and Millington (2022), the SideSafe system appears to be the only system of which indications on sensitivity and specificity are provided, *as well as* a description of how such measures were obtained.

Unit Cost
Data on unit cost are not available.

Availability
Data on system availability are not available. The product website advertises with UK wide installation, which suggests that system availability may be limited outside the UK.

E.31 VIA Technologies

The VIA website notes two systems of interest: the VIA Mobile360 AI Mining Safety Kit and the VIA Mobile360 SVS (Surround View System) AI System. These systems are both based around the same VIA Mobile360 M820 computer, which can process up to 9 camera feeds and merge these into a 360° view of the vehicle surroundings. The manual states that the systems can be augmented with ultrasonic sensors as well as radar sensors, and can perform Blind Spot Detection and Forward Collision Warnings. The two systems appear to differ only in their application to mining vehicles and commercial vehicles respectively.
The company did respond to the initial contact request, but later indicated that their systems did not fall within our scope. They did not respond to further inquiries. Unfortunately, because no information could be obtained on the ultrasonic and radar systems, nor on the HMI, there is insufficient information to evaluate the qualities of these systems, and they are not included in the ratings.

E.32 Vigil Sterling

Vigil Sterling did not respond to contact requests. The following information was extracted from a description on the product website.

E.32.1 SiteSafe NT

Operational Design Domain
The SiteSafe system is primarily intended for off-motorway vehicles, such as mining equipment. Its sensor(s) can be mounted in different locations, making it suitable to monitor the sides or the rear of the vehicle. The system can detect moving and stationary objects. It is not stated whether this includes VRUs.

Implementation

The system makes use of one or two radar sensors, depending on the target application. The sensors have an IP67 protection rating and operate with voltages between 12-30V. The sensor has an adjustable effective range, variable between 1-24m in 8 steps. The system provides warnings by means of dual (i.e., one red, one green) LEDs.
No other information is available.

Scientific Validity

Data on scientific validity are not available.

Unit Cost

Data on unit cost are not available.

Availability

Data on system availability are not available.

E.33 Volvo

Four blind spot monitoring systems were found on Volvo web pages: Blind Spot Detection, Side Collision Avoidance Support, Reversing Information, and Moving Off Information System. Volvo did not respond to contact requests. The first system appears to be available on new Volvo trucks, but is only briefly mentioned on the product page for an Active Driver Assist Forward Collision Warning system (which is outside the scope of the present inventory). As such, it is not known whether this system is an option or if it comes standard with this system, or whether it is available as retrofit option. Moreover, information on the Blind Spot Detection system is very limited. The latter three systems were presented as news stories and did not have a related product page. As such, only the Blind Spot Detection system could be included in this inventory.

E.33.1 Blind Spot Detection

Operational Design Domain

The system description states that it detects when a vehicle is present in the blind spot on the vehicle passenger side, and warns the driver by activating an LED warning light on the right side A-pillar along with an audio response.

Implementation

Data on implementation are not available.

Scientific Validity

Data on scientific validity are not available.

Unit Cost

Data on unit cost are not available.

Availability

Data on system availability are not available.

E.34 Xiamen Autostar Electronics

Three blind spot detection systems by Xiamen Autostar Electronics were identified, all using ultrasonic sensors. The company did not respond to contact requests. The following information was extracted from a description on the product website.

E.34.1 Side Detection Sensor

Operational Design Domain

The Side Detection Sensor system detects objects on the side of the vehicle. The system only works at low driving speeds (threshold not specified), which suggests that the system is intended for turning assistance. The system can be retrofitted to vehicles of categories N2, N3, M2, and M3. Based on imagery, the system appears to function on both rigid and articulated vehicles. No information was available to infer if the system can discern moving objects from stationary objects, nor whether VRUs are detected.

Implementation

An array of four ultrasonic sensors is used, each of which have a horizontal FoV of 60° and a vertical FoV of 30°. The detection depth is configurable at 1m or 3m. Object detection results in an illuminated warning light. Additional activation of the turning signal triggers a warning beep. It is not specified whether the turning signal is derived from the CAN bus or from the analogue turn signal contacts. Driving speed is derived through an internal GPS receiver. The sensors and the ECU all have an IP67 protection rating. Power is drawn from the vehicle's battery, with an operating voltage range of 9-32V. The ECU draws <1.5A current (ultrasonic sensors unspecified).

Scientific Validity

Data on scientific validity are not available.

Unit Cost

Data on unit cost are not available.

Availability

Data on system availability are not available.

E.34.2 OEM Truck Reversing Sensor Commercial Vehicle Parking Sensor

Operational Design Domain

The system is intended for detection of objects behind the vehicle, thus assisting the driver when reversing. It could not be inferred whether the system is able to detect moving objects and whether VRUs are detected. Imagery on the product website suggests that the system can be used with rigid and articulated trucks (N2 and N3 categories) as well as buses (M2, M3). The system is available as retrofit kit.

Implementation

An array of four ultrasonic sensors is used, with a detection zone between 0.3m and 3m depth. The width of the detection zone is not specified. If the reverse gear is used, detected objects are made known by means of an LED display with a built-in buzzer.
The system operates at a voltage of 18-36V, which, according to the wiring diagram, appears to be drawn from a backup light. The ECU is described as "waterproof". Neither ECU, nor sensors are specified with an IP protection rating.

Scientific Validity

Data on scientific validity are not available.

Unit Cost
Data on unit cost are not available.

Availability
Data on system availability are not available.

E.34.3 OEM Truck Reversing Aid Rear View Parking Sensor System
The system is identical to the "OEM Truck Reversing Sensor Commercial Vehicle Parking Sensor" system described above, except that the warning is provided solely by means of a buzzer. No visual warning is provided in the standard retrofit kit, although an LED display is listed as optional component.

E.35 ZF

The portfolio of ZF covers several blind spot detection systems. These were formerly produced by WABCO, which is nowadays part of ZF. ZF initially did not respond to contact requests via web forms on the ZF website. An information request letter was sent to a Dutch ZF sales division after contacting them by phone. However, no information was received by the time of finishing the present report. Therefore, the following information was extracted from a description on the product website, as well as Google search queries which led to WABCO manuals for the Onside system and the Tailguard Assist system.

E.35.1 OnSide

Operational Design Domain
The OnSide system assists drivers of rigid and articulated trucks (N2, N3) with lane changes, by presenting an alert in case moving objects are detected on the co-driver's side. The system is not designed to warn about cyclists or pedestrians, and no alerts are provided when the driving speed is below 24km/h. The system is available as OEM solution.

Implementation
A single radar sensor with a 160° horizontal FoV is used to detect moving objects in a detection zone with a depth of 2.7m. Alongside the vehicle, the detection zone reaches 4m in front of the sensor (and thus partially in front of the vehicle) and 10m rearwards. LEDs are illuminated if a moving object is detected. A buzzer presents 'triple chirps' if, in addition, the turn signal is activated. For this reason, the system requires turn signal information, next to J1939 CAN High and J1939 CAN Low bus access. To diagnose malfunctions, the manual states: "If there is a malfunction and the system cannot provide assistance, the LED indicator (mounted on the A-pillar) may not light up at all, may continuously be illuminated or may blink intermittently."

Scientific Validity
Data on scientific validity are not available.

Unit Cost
Data on unit cost are not available.

Availability
Data on system availability are not available.

E.35.2 TailGuard Assist

Operational Design Domain

TailGuard Assist is a rear collision avoidance system for rigid and articulated trucks and buses (M3, N2, N3). The system detects moving and stationary objects (including VRUs) when reversing up to a speed of 9km/h. The system initially warns, and intervenes by braking if objects are too close. The system is compliant with UNECE R13 (braking systems for commercial vehicles) and available as OEM solution.

Implementation

Object detection is based on an array of ultrasonic sensors with a detection depth of at most 4m (precision: 0.25m). The width of the array is not specified, but likely depends on the number of sensors used. Between two and six sensors can be used, depending on the application (e.g., sensors at high altitudes may be used for docking manoeuvres). Detected objects are communicated by means of a dedicated display, on which the number of coloured bars signifies the proximity to an object. Auditory warnings are presented as well, the repetition rate of which increases with decreasing distance to the object. The system automatically intervenes by braking if the object comes too close. The threshold for this distance is configurable between 0.5m and 2m.

Power is obtained through the vehicle's battery (operating voltage: 11.5-24V). Besides power, the system uses reverse gear and driving speed information through the CAN bus. In case a trailer is connected (e.g., a tractor trailer combination), a Trailer-EBS E2 connection is used as well.

According to the manual, the system does not require maintenance. However, in case of system error messages or an assumed malfunction, the ultrasonic sensors must be checked for soiling first and cleaned as required.

Scientific Validity

Numeric data on scientific validity are not available. The manual states that the system has been tested by TÜV Nord. Furthermore, the manual states that: “Ultrasound is best reflected by smooth surfaces that are positioned at a right angle to the direction of the sound. Small and unfavourable surfaces such as meshed structures, furry or hairy surfaces at an oblique angle to the direction of the sound are not detected so easily."

Unit Cost

Data on unit cost are not available.

Availability

Data on system availability are not available.

E.35.3 GSR II ADAS Suite

Operational Design Domain

The GSR II ADAS Suite is a modular collection of systems designed to meet the requirements of the updated General Safety Regulation of the European Union. It is comprised of, amongst others, MOIS, BSIS and REIS to help detect and protect pedestrians and cyclists. The system appears to be available for rigid and articulated vehicles (categories N2, N3, M2, M3).

Implementation

The systems can be configured to provide warnings when objects are detected and/or to automatically intervene. Data on implementation are not available.

Scientific Validity

Data on scientific validity are not available.

Unit Cost

Data on unit cost are not available.

Availability

Data on system availability are not available.

Appendix F BSMS requirements in UNECE regulations

Blind spot monitoring systems

Guaranteed performance by meeting UNECE requirements

Dr. Ir. Reinier Jansen, Dr. Ksander de Winkel

The Hague – May 25th, 2023

1

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- Introduction to blind spot zones
- Blind spot monitoring system (BSMS) rationale and classes
- Building an inventory of existing BSMSs
  - Limited information available
  - Guaranteed performance by meeting UNECE requirements
- Overview of UNECE requirements for BSMSs
- Conclusion and recommendations on identifying the best BSMSs

2

Introduction to blind spot zones

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Blind spot zones

- Blind spots are areas around a vehicle which are blocked from direct view due to the construction of the vehicle.
- Trucks, busses and mining vehicles feature several blind spots on the front, side and rear of the vehicle.

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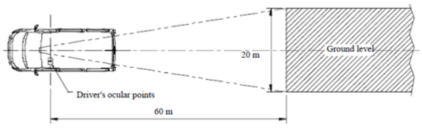
Blind spot zones

- UNECE Regulation R46 describes six blind spot zones for indirect viewing devices (e.g., mirrors, camera systems).
- Class I: Rear-view device
  - **Optional** for trucks and busses



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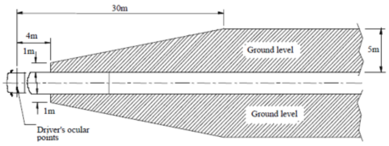
Blind spot zones

- UNECE Regulation R46 describes six blind spot zones for indirect viewing devices (e.g., mirrors, camera systems).
- Class II: Main rear-view
  - **Compulsory** for trucks and busses



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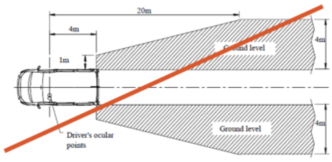
Blind spot zones

- UNECE Regulation R46 describes six blind spot zones for indirect viewing devices (e.g., mirrors, camera systems).
- Class III: Main rear-view
  - **Not permitted** for trucks and busses



Source: UNECE regulation R46

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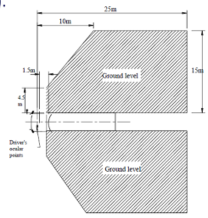
Blind spot zones

- UNECE Regulation R46 describes six blind spot zones for indirect viewing devices (e.g., mirrors, camera systems).
- Class IV: Wide-angle
  - **Compulsory** for trucks
  - Optional for busses



Source: UNECE regulation R46

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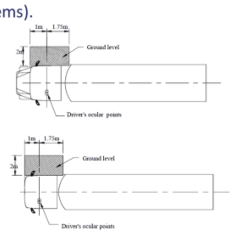
Blind spot zones

- UNECE Regulation R46 describes six blind spot zones for indirect viewing devices (e.g., mirrors, camera systems).
- Class V: Close-proximity
  - **Compulsory** for trucks
  - Optional for busses



Source: UNECE regulation R46

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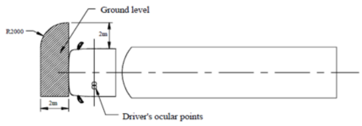
Blind spot zones

- UNECE Regulation R46 describes six blind spot zones for indirect viewing devices (e.g., mirrors, camera systems).
- Class VI: Front-view
  - **Compulsory** for heavy trucks (N2 > 7.5t, N3)
  - Optional for busses and light trucks (N2 ≤ 7.5t)



Source: UNECE regulation R46

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SWOV

BSMS rationale and classes

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BSMS rationale

- Blind spot related crashes still occur, despite compulsory indirect viewing devices. (Pokorny et al. 2017; Talbot et al., 2014)
- Drivers may not always check their mirrors when needed. (Jansen & Varotto, 2022)
- BSMSs are designed to assist drivers in becoming aware of other road users.
- BSMS components:
  - Sensor (e.g., radar) - to capture an image of a blind spot zone
  - Algorithm - to identify objects (e.g., road users) within the captured image
  - Display (e.g., LED lights, buzzer) - to warn the driver about object presence
  - Intervention (e.g., braking) - if the driver fails to react *(optional component)*

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BSMS rationale

- No studies on the effect of BSMSs in trucks, busses, or mining/construction vehicles on traffic safety are known, but BSMSs in passenger cars have been shown to reduce crash risk. (Cicchino, 2017; Cicchino, 2018; Cicchino, 2019)
- This suggests BSMSs have the potential to improve safety of trucks, busses, and mining/construction vehicles.

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BSMS classes

UNECE	Function	Purpose	Vehicle Type
R159	Moving Off Information System (MOIS)	Helps avoid collisions with pedestrians when moving off	M2, M3, N2, N3
R151	Blind Spot Information System (BSIS)	Helps avoid collisions when cyclists are pesent near the passenger side of the vehicle	M2, M3, N2, N3
R158	Reversing Information System (REIS)	Helps avoid collisions during reversing manoeuvers	M2, M3, N2, N3

Source: https://www.camox-uk.com/post/un-gsr-general-safety-regulations-2024

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Building an inventory of existing BSMSs

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BSMS inventory

- Aim: identify and compare commercially available BSMSs for trucks, busses and construction/mining vehicles (SWOV report: De Winkel et al., 2023)
- Google search queries
  - Eligible systems: 64 by 35 companies
- Companies contacted for information
  - Potential business case shared (e.g., 10000 trucks in 5 years)
  - Response: 12 companies on 17 systems
- Information mostly gathered through product websites and online manuals
  - Information on, a.o., system detection performance is often missing (e.g., proportion of correct detection, false alarm rate, testing methodology)

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BSMS inventory

- Quality based system ranking on 7 criteria:
  - VRU detection: can the BSMS detect vulnerable road users, e.g., pedestrians and cyclists? (bonus if yes)
  - Ingress Protection rating (higher is better)
  - Sensor horizontal and vertical field of view* (more is better)
  - Sensor range* (more is better)
  - UNECE compliance with R151, R158 and/or R159 (bonus if compliant)
  - Triggered system: are systems activated only in certain conditions (thus reducing false alarm rates)? (bonus if yes)
  - Unit cost (less is better)

* Sensor specifications were used as proxy for detection performance, but these cannot replace criteria such as false alarm rate.

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BSMS inventory

- No top-10 ranking system featured a complete set of information on all 7 criteria.
- Due to missing information no definitive recommendation on the best performing system (in terms of traffic safety) can be given.
- Compliance with UNECE regulations (R151, R158, and/or R159) is not legally required for retrofit systems, but indicates an acceptable performance has been demonstrated. Therefore, compliance could be viewed as a minimum requirement for *all* BSMSs in practice.
- Note: systems of which no compliance is reported may in fact comply with the underlying requirements of these regulations.

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Overview of UNECE requirements for BSMSs

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UNECE requirements for BSMSs

- UNECE regulations R151/R158/R159 describe BSMS-legislation for type approval of vehicles.

Agreement

Concerning the Adoption of Harmonized Technical United Nations Regulations for Wheeled Vehicles, Equipment and Parts which can be Fitted and/or be Used on Wheeled Vehicles and the Conditions for Reciprocal Recognition of Approvals Granted on the Basis of these United Nations Regulations*

(Revision 3, including the amendments which entered into force on 14 September 2017)

Addendum 150 – UN Regulation No. 151

Date of entry into force as an annex to the 1958 Agreement: 15 November 2019

Uniform provisions concerning the approval of motor vehicles with regard to the Blind Spot Information System for the Detection of Bicycles

This document is meant purely as documentation tool. The authentic and legal binding text is: ECE/TRANS/WP.29/2019/28.

UNITED NATIONS

Source: UNECE regulation R151

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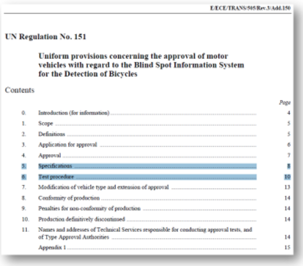
UNECE requirements for BSMSs

- UNECE regulations R151/R158/R159 describe BSMS-legislation for type approval of vehicles.
- *'Specifications'* describes what a BSMS should do.
- *'Test procedure'* describes how a BSMS should be assessed.



E/ECE/TRANS/505/Rev.3/Add.150

UN Regulation No. 151

Uniform provisions concerning the approval of motor vehicles with regard to the Blind Spot Information System for the Detection of Bicycles

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Source: UNECE regulation R151

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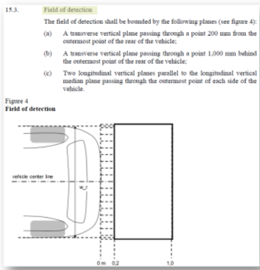
UNECE requirements for BSMSs

- Example 1: a specification of the field of detection can be attributed to sensor range (depth, width).



Colored fields are referred to in Slide 25

Source: UNECE regulation R158

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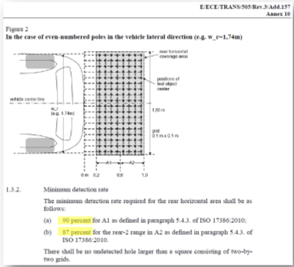
UNECE requirements for BSMSs

- Example 1: a specification of the field of detection can be attributed to sensor range (depth, width).
- Example 2: minimum detection rate can be attributed to sensitivity (proportion of correct detections).



Coloured fields are referred to in Slide 25 — Source: UNECE regulation R158

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UNECE requirements for BSMSs

- Example 1: a specification of the field of detection can be attributed to sensor range (depth, width).
- Example 2: minimum detection rate can be attributed to sensitivity (proportion of correct detections).
- Example 3: the system should be able to perform a self-check and warn the driver in case of malfunction.

5.3. Automatic Deactivation

5.3.1. The MOIS shall automatically deactivate if it malfunctions or cannot operate properly due to its sensor devices becoming contaminated by ice, snow, mud, dirt or similar material. The MOIS may also automatically deactivate due to ambient light conditions below that specified in paragraph 5.2.1.

5.3.2. Automatic deactivation shall be indicated by the failure warning signal specified in paragraph 5.8.

5.3.3. The MOIS shall automatically deactivate when the normal function of the sensors is verified. This shall be tested in accordance with the provisions of paragraphs 6.8 (failure detection test) and 6.9. (automatic deactivation test).

Coloured fields are referred to in Slide 25 — Source: UNECE regulation R159

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Summary of requirements for BSMSs*

Requirement	BSIS (R151)	REIS (R158)	MOIS (R159)
Smallest target size in test	Bicycle with cyclist	Cylinder (h: 0.8m, d: 0.3m)	Child cyclist
Sensor detection range lateral	2m (static test type 1)	Vehicle width	Vehicle width +0.5m on either side
Sensor detection range longitudinal	7.77m from front of vehicle projected backwards (static test type 2)	0.2-1.0m	1.0-3.7m (depending on cabin design)
System sensitivity (correct detection)	Not specified (implicitly: 100%)	0.2-0.6m: detection rate > 90% 0.6-1.0m: detection rate > 87% Objects larger than 0.2x0.2m: detection rate 100%	Not specified (implicitly: 100%)
System specificity (correct rejection)	Minimize false-positives of non-VRU objects	Not specified	Minimize false-positives of objects outside detection area
Staged warning	Inform on proximity, warn on collision	Two or more levels on proximity (for auditory warnings)	Inform on proximity, warn on collision
Triggered system	Not specified	Activation when backing	Activation with forward speed <10km/h
Multimodal signal	Unimodal allowed	At least 2 modalities	At least 2 modalities
Failure detection	Mandatory, with automatic deactivation and failure warning signal	Mandatory, with automatic deactivation and failure warning signal	Mandatory, with automatic deactivation and failure warning signal

* This table presents an excerpt of requirements found in UNECE regulations R151, R158, and R159, interpreted in terms of the criteria used in the inventory in De Winkel et al. (2023)

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SWOV

Conclusion and recommendations on identifying the best BSMSs

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Conclusion

- EU 2144/2019: compliance with BSMS-related UNECE regulations (R151, R158, R159) is required for type approval of new trucks since July 6th 2022.
- Compliance is not legally required for retrofit systems, but indicates an acceptable performance has been demonstrated. Therefore, compliance could be viewed as a minimum requirement for *all* BSMSs in practice.
- Note: systems of which no compliance is reported may in fact comply with these regulations
  - The best performing system may be missed if selection is *only* made based on UNECE compliance.
  - Systems that adhere to the same requirements without an official 'compliance label' may be considered as eligible as well.

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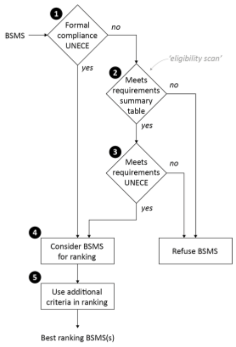
Recommendations

- Confirm whether a prospective BSMS has a formal UNECE compliance label (#1)
- If not, use the summary table (slide 25) to perform a quick eligibility scan (#2)
- If the subset of UNECE requirements in the summary table are met, check whether the BSMS meets *all* UNECE requirements (#3)
- ...recommendations continue on next slide



R151 on BSIS: for bicyclists next to the vehicle when turning
R158 on REIS: for road users behind the vehicle when reversing
R159 on MOIS: for road users in front of the vehicle when moving off

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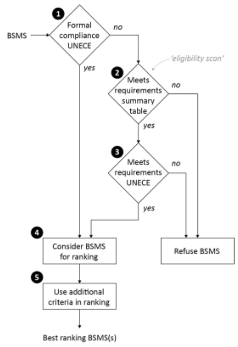
Recommendations

- Only consider BSMS that either have a formal compliance label, or (without a label) those which meet the underlying requirements (#4)
- Use additional criteria (e.g., ingress protection, cost)* to identify the best ranking BSMS(s) (#5).



R151 on BSIS: for bicyclists next to the vehicle when turning
R158 on REIS: for road users behind the vehicle when reversing
R159 on MOIS: for road users in front of the vehicle when moving off

* Additional criteria are described in SWOV BSMS report by De Winkel et al. (2023)

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