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Automated Vehicles to Evolve to a New Urban Experience

DELIVERABLE

D9.3 Roadmap for cost-attractiveness

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Acronyms

AI	Artificial Intelligence
AM	Automated Minibus
AMPT	Automated Minibuses for Public Transport
API	Application Programming Interface
AV	Automated Vehicle
AVENUE	Autonomous Vehicles to Evolve to a New Urban Experience
BMVI	Bundesministerium für Verkehr und Digitales
CPT	Conventional Public Transport
DESI	Digital Economy and Social Index
DLT	Distributed Ledger Technology
DMA	Digital Market Act
DNN	Deep Neural Networks
EU	European Union
GAFAM	Google, Apple, Facebook, Amazon
GDPR	General Data Protection Regulation
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IMU	Inertial Measurement Unit
ITS	Intelligent Transport System
LCA	Life Cycle Assessment
LiDAR	Laser Detection and Ranging
MAAMA	Meta, Alphabet, Amazon, Microsoft, Apple
MaaS	Mobility as a Service
NGO	Non-Governmental Organization
ÖBB	Österreichische Bundesbahnen
PRM	People with Reduced Mobility
PTA	Public Transport Authorities
PTO	Public Transport Operator
RTK	Real-Time Kinematic Positioning
SUMP	Sustainable Urban Mobility Plans
TÜV	Technischer Überwachungsverein

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Executive Summary

The current Deliverable aims at providing the methodology and findings related to the CBA analysis conducted for smart city infrastructure and technologies (both V2V and V2I) that can significantly increase road safety with the introduction of AVENUE autonomous shuttles on the road, used for Public Transport operations.

Based on an extensive list of C-ITS services, ten key safety systems/solutions with benefits for the operator have been recognized and have turned to monetary values. This was achieved with a Cost Benefit Analysis that has been applied in order to select the most cost-effective solutions among them, enhancing road safety. Within this study, the main indices of NPV, IRR and PayBack Period, are calculated for each of the ten solutions. An evaluation period of five years has been chosen and the fleet is considered to increase by one shuttle per year. According to the CBA results, both NPV and IRR are positive for every solution.

Chapter 2 explains the methodology used and Chapter 3 provides all the baseline calculations for the analysis, while Chapter 4 attempts a comparison of the results among the different solutions. Recommendations for implementing SAFESTRIP system to AVENUE demonstrations can be found in Chapter 5. Concluding remarks are presented in Chapter 6.

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1 Introduction

AVENUE aims to design and carry out full-scale demonstrations of urban transport automation by deploying, for the first time worldwide, fleets of Automated minibuses in low to medium demand areas of 4 European demonstrator cities (Geneva, Lyon, Copenhagen, and Luxembourg) and 2 to 3 replicator cities. The AVENUE vision for future public transport in urban and suburban areas, is that Automated vehicles will ensure safe, rapid, economic, sustainable, and personalised transport of passengers. AVENUE introduces disruptive public transportation paradigms based on demand, door-to-door services, aiming to set up a new model of public transportation, by revisiting the offered public transportation services, and aiming to suppress prescheduled fixed bus itineraries.

Vehicle services that substantially enhance the passenger experience as well as the overall quality and value of the service will be introduced, also targeting elderly people, people with disabilities and vulnerable users. Road behaviour, security of the Automated vehicles and passengers' safety are central points of the AVENUE project.

At the end of the AVENUE project four-year period the mission is to have demonstrated that Automated vehicles will become the future solution for public transport. The AVENUE project will demonstrate the economic, environmental, and social potential of Automated vehicles for both companies and public commuters while assessing the vehicle road behaviour safety.

1.1 On-demand Mobility

Public transportation is a key element of a region's economic development and the quality of life of its citizens.

Governments around the world are defining strategies for the development of efficient public transport based on different criteria of importance to their regions, such as topography, citizens' needs, social and economic barriers, environmental concerns, and historical development. However, new technologies, modes of transport and services are appearing, which seem very promising to the support of regional strategies for the development of public transport.

On-demand transport is a public transport service that only works when a reservation has been recorded and will be a relevant solution where the demand for transport is diffuse and regular transport is inefficient.

On-demand transport differs from other public transport services in that vehicles do not follow a fixed route and do not use a predefined timetable. Unlike taxis, on-demand public transport is usually also not individual. An operator or an automated system takes care of the booking, planning and organization.

It is recognized that the use and integration of on-demand Automated vehicles has the potential to significantly improve services and provide solutions to many of the problems encountered today in the development of sustainable and efficient public transport.

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1.2 Fully Automated Vehicles

A self-driving car, referred in the AVENUE project as a **Fully Automated Vehicle** (**AV**), or as Autonomous Vehicle, is a vehicle that can sense its environment and moving safely with no human input.

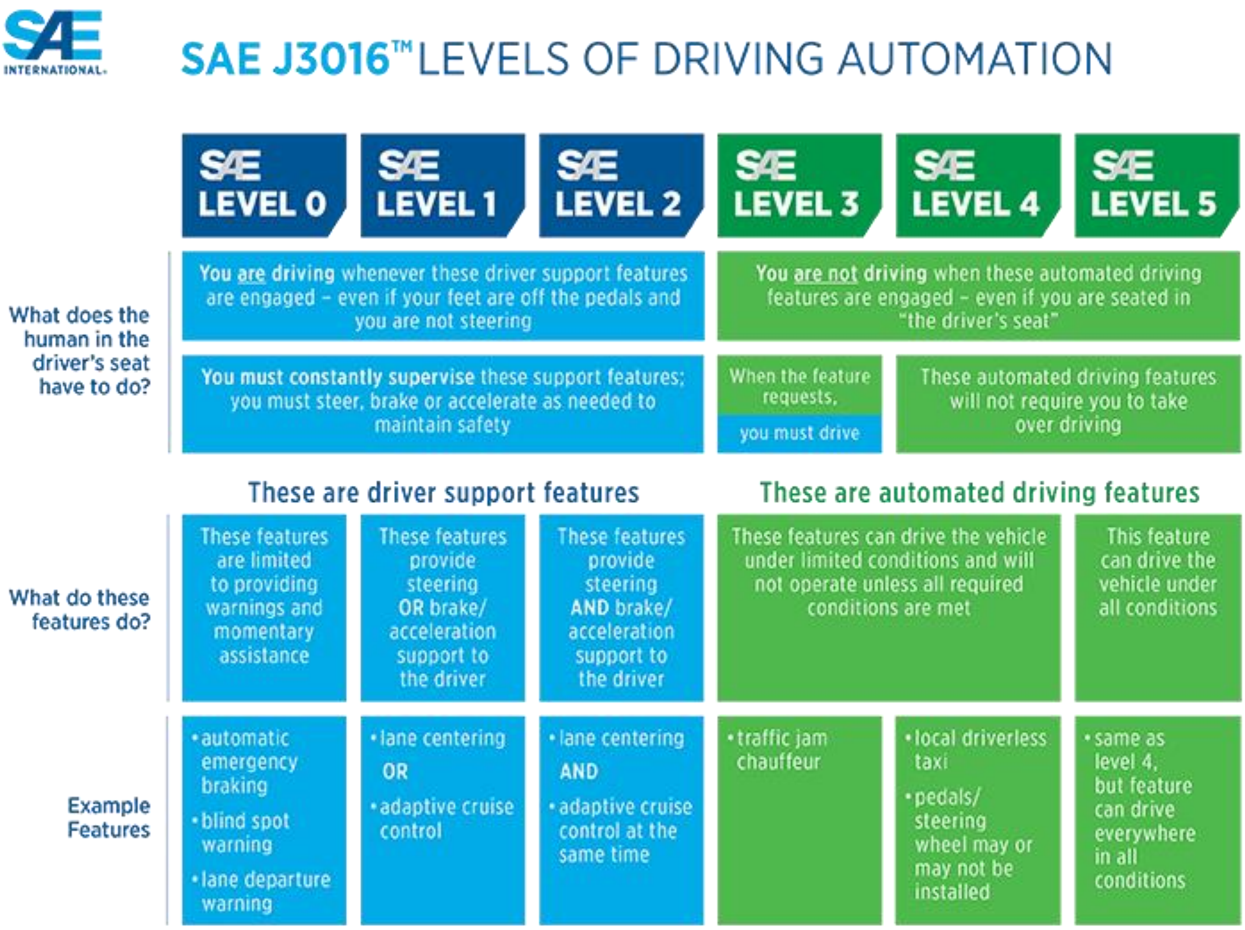
The terms *automated vehicles* and *autonomous vehicles* are often used together. The Regulation 2019/2144 of the European Parliament and of the Council of 27 November 2019 on type-approval requirements for motor vehicles defines "automated vehicle" and "fully automated vehicle" based on their autonomous capacity:

An "automated vehicle" means a motor vehicle designed and constructed to move autonomously for certain periods of time without continuous driver supervision but in respect of which driver intervention is still expected or required

"Fully automated vehicle" means a motor vehicle that has been designed and constructed to move autonomously without any driver supervision

In AVENUE we operate ***Fully Automated minibuses for public transport***, (previously referred as Autonomous shuttles, or Autonomous buses), and we refer to them as simply *Automated minibuses* or *the AVENUE minibuses.*

In relation to the SAE levels, the AVENUE project will operate SAE Level 4 vehicles.


SAE INTERNATIONAL

SAE J3016™ LEVELS OF DRIVING AUTOMATION

	SAE LEVEL 0	SAE LEVEL 1	SAE LEVEL 2	SAE LEVEL 3	SAE LEVEL 4	SAE LEVEL 5
What does the human in the driver's seat have to do?	You **are driving** whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			You **are not driving** when these automated driving features are engaged – even if you are seated in "the driver's seat"		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
	These are driver support features			These are automated driving features		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering OR brake/ acceleration support to the driver	These features provide steering AND brake/ acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met		This feature can drive the vehicle under all conditions
Example Features	• automatic emergency braking • blind spot warning • lane departure warning	• lane centering OR • adaptive cruise control	• lane centering AND • adaptive cruise control at the same time	• traffic jam chauffeur	• local driverless taxi • pedals/ steering wheel may or may not be installed	• same as level 4, but feature can drive everywhere in all conditions

Table 1: SAE Driving Automation levels (©2020 SAE International)

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1.2.1 Automated vehicle operation overview

We distinguish in AVENUE two levels of control of the AV: micro-navigation and macro-navigation. Micro navigation is fully integrated in the vehicle and implements the road behaviour of the vehicle, while macro-navigation is controlled by the operator running the vehicle and defines the destination and path of the vehicle, as defined the higher view of the overall fleet management.

For micro-navigation Automated Vehicles combine a variety of sensors to perceive their surroundings, such as 3D video, LIDAR, sonar, GNSS, odometry and other types of sensors. Control software and systems, integrated in the vehicle, fusion and interpret the sensor information to identify the current position of the vehicle, detecting obstacles in the surround environment, and choosing the most appropriate reaction of the vehicle, ranging from stopping to bypassing the obstacle, reducing its speed, making a turn etc.

For the Macro-navigation, that is the destination to reach, the Automated Vehicle receives the information from either the in-vehicle operator (in the current configuration with a fixed path route), or from the remote-control service via a dedicated 4/5G communication channel, for a fleet-managed operation. The fleet management system considers all available vehicles in the services area, the passenger request, the operator policies, the street conditions (closed streets) and send route and stop information to the vehicle (route to follow and destination to reach).

1.2.2 Automated vehicle capabilities in AVENUE

The Automated vehicles employed in AVENUE fully and automatically manage the above defined, micro-navigation and road behaviour, in an open street environment. The vehicles are automatically capable to recognise obstacles (and identify some of them), identify moving and stationary objects, and automatically decide to bypass or wait behind them, based on the defined policies. For example, with small changes in its route the AVENUE minibus is able to bypass a parked car, while it will slow down and follow behind a slowly moving car. The AVENUE mini-buses are able to handle different complex road situations, like entering and exiting round-about in the presence of other fast running cars, stop in zebra crossings, communicate with infrastructure via V2I interfaces (ex. red light control).

The minibuses used in the AVENUE project technically can achieve speeds of more than 60Km/h. However, this speed cannot be used in the project demonstrators for several reasons, ranging from regulatory to safety. Under current regulations the maximum authorised speed is 25 or 30 Km/h (depending on the site). In the current demonstrators the speed does not exceed 23 Km/h, with an operational speed of 14 to 18 Km/h. Another, more important reason for limiting the vehicle speed is safety for passengers and pedestrians. Due to the fact that the current LIDAR has a range of 100m and the obstacle identification is done for objects no further than 40 meters, and considering that the vehicle must safely stop in case of an obstacle on the road (which will be “seen” at less than 40 meters distance) we cannot guarantee a safe braking if the speed is more than 25 Km/h. Note that technically the vehicle can make harsh break and stop with 40 meters in high speeds (40 -50 Km/h) but then the break would too harsh putting in risk the vehicle passengers. The project is working in finding an optimal point between passenger and pedestrian safety.

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Due to legal requirements a **Safety Operator** must always be present in the vehicle, able to take control any moment. Additionally, at the control room, a **Supervisor** is present controlling the fleet operations. An **Intervention Team** is present in the deployment area ready to intervene in case of incident to any of the minibuses. Table 2 provides an overview of the AVENEU sites and ODDs.

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	Summary of AVENUE operating sites demonstrators							
	TPG		Holo		Keolis	Sales-Lentz		
	Geneva		Copenhagen	Oslo	Lyon	Luxembourg		
Site	Meyrin	Belle-Idée	Nordhavn	Ormøya	ParcOL	Pfaffental	Contern	Esch sur Alzette
Funding	TPG	EU + TPG	EU + Holo	EU + Holo	EU + Keolis	EU + SLA	EU + SLA	EU + SLA
Start date of project	August 2017	May 2018	May 2017	August 2019	May 2017	June 2018	June 2018	February 2022
Start date of trial	July 2018	June 2020	September 2020	December 2019	November 2019	September 2018	September 2018	April 2022
Type of route	Fixed circular line	Area	Fixed circular line	Fixed circular line	Fixed circular line	Fixed circular line	Fixed circular line	Fixed circular line
Level of on-demand service*	Fixed route / Fixed stops	Flexible route / On-demand stops	Fixed route / Fixed stops	Fixed route / Fixed stops	Fixed route/Fixed stops	Fixed route / Fixed stops	Fixed route / Fixed stops	Fixed route / Fixed stops
Route length	2,1 km	38 hectares	1,3 km	1,6 km	1,3 km	1,2 km	2,3 km	1 km
Road environment	Open road	Semi-private	Open road	Open road	Open road	Public road	Public road	Main pedestrian road
Type of traffic	Mixed	Mixed	Mixed	Mixed	Mixed	Mixed	Mixed	Pedestrians, bicycles, delivery cars
Speed limit	30 km/h	30 km/h	30 km/h	30 km/h	8 to 10 km/h	30 km/h	50 km/h	20 km/h
Roundabouts	Yes	Yes	No	No	Yes	No	No	No
Traffic lights	No	No	No	No	Yes	Yes	Yes	No
Type of service	Fixed line	On demand	Fixed line	Fixed line	Fixed line	Fixed line	Fixed line	On Demand
Concession	Line (circular)	Area	Line (circular)	Line (circular)	Line (circular)	Line (circular)	Line (circular)	Line (circular)
Number of stops	4	> 35	6	6	2	4	2	3
Type of bus stop	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Bus stop infrastructure	Yes	Sometimes, mostly not	Yes	Yes	Yes	Yes	Yes	Yes

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Number of vehicles	1	3-4	1	2	2	2	1	1
Timetable	Fixed	On demand	Fixed	Fixed	Fixed	Fixed	Fixed	On-demand
Operation hours	Monday-Friday (5 days)	Sunday-Saturday (7 days)	Monday-Friday (5 days)	Monday-Sunday (7 days)	Monday-Saturday (6 days)	Tuesday & Thursday Saturday, Sunday & every public holiday	Monday - Friday	Monday – Saturday
Timeframe weekdays	06:30 – 08:30 / 16:00 – 18:15	07:00 – 19:00	10:00 – 18:00	7:30 – 21:30	08:30 – 19:30	12:00 – 20h00	7:00 – 9:00 16:00 – 19:00	11:00 – 18:00 11:00 – 18:00
Timeframe weekends	No service	07:00 – 19:00	No service	9:00 – 18:00	08:30 – 19:30	10:00 – 21:00	No Service	On Suterday only
Depot	400 meters distance	On site	800 meters distance	200 meters distance	On site	On site	On site	500 m distance
Driverless service	No	2021	No	No	No	No	No	No
Drive area type/ODD	B-Roads	Minor roads/parking	B-Roads/minor roads	B-Roads	B-Roads	B-Roads	B-Roads/parking	
Drive area geo/ODD	Straight lines/plane	Straight lines/ plane	Straight lines/ plane	Curves/slopes	Straight Lines/ plane	Straight lines/ plane	Straight lines/ plane	Straight lines / plane
Lane specification/ODD	Traffic lane	Traffic lane	Traffic lane	Traffic lane	Traffic lane	Traffic lane	Traffic lane	Open area
Drive area signs/ODD	Regulatory	Regulatory	Regulatory, Warning	Regulatory	Regulatory	Regulatory	Regulatory	Regulatory
Drive area surface/ODD	Standard surface, Speedbumps	Standard surface, Speedbumps	Standard surface Speedbumps, Roadworks	Frequent Ice, Snow	Standard surface, Potholes	Standard surface	Standard surface	Standard Surrface

Table 2: Summary of AVENUE operating site (+ODD components)

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1.3 Preamble – the AVENUE Vision for a Future Mobility

Using innovative C-ITS systems can contribute to prevent and reduce the number of road related accidents and improve road safety. Thus, key technologies/systems that can significantly increase road safety are identified within this Deliverable and a Cost Benefit Analysis has been applied to identify the most cost-effective solutions among them that can enhance road safety. The technologies selected are C-ITS services and make use of the communication between the vehicles or between vehicles and infrastructure (V2V and V2I) in order to timely inform the operators of any unexpected events across their route. These systems entail benefits for the AVENUE shuttle operators that are turned to monetary values. Furthermore, the SAFESTRIP infrastructure-based system is added in the list, as an add-on to the existing AVENUE services.

The current analysis has been conducted from the perspective of the monetarized benefits that are primarily associated to the operation of the equipped autonomous vehicles fleet itself and, thus, are returned primarily and directly to the AVENUE shuttle operators. Nevertheless, this perspective, along with the estimated costs and benefits, is directly associated to the OEM, as it is evident that the more profitable the operation proves for the operator, the more beneficial the initial investment will equally prove on the OEM side. The final outcome of the CBA study aims to reveal upon which systems/solutions the investment can prove profitable for the AVENUE shuttle operators.

2 Methodology

A preliminary list of C-ITS technologies that deploy V2V and V2I communications were identified, based on a relevant literature review on reports from C-Roads platform [1]. Then a short-down list of technical solutions/systems was extracted, based upon their technical feasibility and impact on road safety.

In addition, the SAFESTRIP system is included in the list, due to its disruptive technology and appropriateness for automated vehicles (detailed info is provided in section 2.3); thus it is examined as potential system to be implemented in AVENUE demonstrators, on top of existing technologies. The ten selected solutions are listed below:

1. SAFESTRIP system
2. Emergency electronic brake light
3. Emergency vehicle approaching
4. Hazardous location notification
5. Slow or stationary vehicle(s) warning
6. In-vehicle signage
7. Probe vehicle data

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8. Green Light Optimal Speed Advisory / Time to Green
9. Signal violation/Intersection safety
10. Vulnerable road user protection

Specifically for the SAFESTRIP solution, it abides to the requirements and gaps identified in Deliverable 2.15, namely vehicle (ON3, ON6) and software (ON6) related gaps (see the tables of sections 4.2.2 and 4.2.3). The monetarized benefits for each of the above systems are calculated and presented in paragraph 2.3.

2.1 Key business scenario

The Personnel Monthly (PM) Rate is assumed to be 4500€ and has been used for the calculations below. The total fleet number is decided to be 5 and the period 5 years. The reason behind this decision is the fact that the technologies are very new, so the public probably needs some time to adopt them and thus the investment cannot be bigger than one shuttle per year.

The Development cost for the SW, is higher for the first vehicle, but in order to facilitate the calculations, it is divided among a fleet of 5 vehicles. This means that for each vehicle the cost is the same.

	Solution/system	**Integration cost (HW)**	**Development cost/ Integration cost (SW)**	**Overall installation effort (in MMs)**	**Operational cost (10%)**	**Maintenance cost (10%)**	**Extra Cost**
1.	SAFESTRIP	4	2	4.5	1.05	1.05	2.35 every 1.5 km
2.	Emergency electronic brake light	10	7	4.5	2.15	2.15	-
3.	Emergency vehicle approaching	10	3	4.5	1.75	1.75	-
4.	Hazardous location notification	10	3	4.5	1.75	1.75	-
5.	Slow or stationary vehicle(s) warning	10	3	4.5	1.75	1.75	-
6.	In-vehicle signage	10	3	4.5	1.75	1.75	-
7.	Probe vehicle data	10	3	4.5	1.75	1.75	-
8.	Green Light Optimal Speed Advisory /Time to Green	10	7	4.5	2.15	2.15	-

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	Solution/system	Integration cost (HW)	Development cost/ Integration cost (SW)	Overall installation effort (in MMs)	Operational cost (10%)	Maintenance cost (10%)	Extra Cost
9.	Signal violation/ Intersection safety	10	3	4.5	1.77	1.77	30
10.	Vulnerable road user protection	10	3	4.5	1.77	1.77	50

Table 3: Cost per technical solution/system (in K Euros)

The extra cost in the above table is related to the infrastructure and is applied once per solution/system. Specifically, in case of Signal violation/Intersection safety and vulnerable road user protection, the costs are related to the required installation at the traffic lights. In case of the SAFESTRIP system, the relevant cost is for the sub-systems that have to be installed on the pavement.

2.2 Key indices

The CBA methodology applied encompasses the calculation of key indices, namely: the **Net Present Value (NPV)**, the **Internal Rate of Return (IRR)** and the **Payback period** [2][3].

NPV is defined as the difference between the present value of cash inflows and the present value of cash outflows over a period of time. Specifically for the NPV the equation given is:

$$NPV = \sum_{t=1}^{n} \frac{R_t}{(1+i)^t} \quad (1)$$

where:

Rt= Net cash inflow- outflows during a single period t

i= Discount rate of return that could be earned in alternative investments – European bank

t= Number of timer periods

IRR is a metric used to estimate the profitability of potential investments. For the Internal Rate of Return the equation given is as follows:

$$0 = \text{NPV} = \sum_{t=1}^{T} \frac{C_t}{(1+IRR)^t} - C_0 \quad (2)$$

where:

C_t= Net cash inflow during the period t

C_0= Total initial investment costs

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IRR= The internal rate of return

t= The number of time periods

The **payback period** refers to the amount of time it takes to recover the cost of an investment or how long it takes for an investor to hit breakeven.

The net cash inflow and outflow are calculated as follows:

Net cash inflow = Associated to the solution monetarized internal benefits (3)

Net cash outflow = Investment cost of h/w + development effort or s/w + installation effort + annual operational cost + annual maintenance cost (4)

It should be stressed that whenever we refer to investment costs herein, we assume the sum of investment cost of h/w, the development effort and the installation effort.

Total investment costs =Investment cost (h/w) + overall development effort or s/w + installation effort (5)

All the above mentioned costs are listed in Table 3.

The operational and maintenance costs are assumed to be 10% of the total investment costs on an annual basis by average for Years 1-5. **Operational costs** relate to the power consumption cost by the equipment, the data transfer cost via internet connection, the operator's server for hosting logs, the operator's personnel effort to monitor vehicles and logs (if required), while **maintenance costs** relate to costs associated with software update and replacements needed.

2.3 Monetarized benefits per system

The objective of the current CBA study is to estimate the investment for a fleet of 5 vehicles, within an evaluation period of 5 years. From literature, it is known that for the operator, in case of an incident, the cost of life is 1.700 k€, 17 k€ is the cost of a severe injury and 100k€ the cost of bus destroy [4].

The monetarized benefits per safety system/solution follow in the sections below.

2.3.1 SAFESTRIP

SAFESTRIP project developed a disruptive technology that embedded C-ITS applications into existing road infrastructure, including I2V and V2I communications as well as VMS/VSL functions into low-cost, integrated strip markers on the road. These strips support ITS services and apps as they provide personalized in-vehicle messages for all road users (trucks, cars and vulnerable road users, such as PTWs riders) and all vehicle generations (non-equipped, C-ITS equipped, autonomous), at a reduced maintenance cost, fully recyclability and containing added-value services, as well as supporting real-time predictive road maintenance functions. SAFESTRIP system implements two complementary as well as alternative solutions: one that addresses equipped vehicles (namely, intelligent vehicles with on board sensors and C-ITS or automation applications) and one to address non-equipped vehicles (the great majority of current vehicle fleets, including also vehicles that are very difficult to equip with rich on-board

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sensorial platforms, like Powered Two Wheels) [5][6]. SAFESTRIP system consists of the following parts:

- Strips
- On-Road Units (ORU)
- Road Side Unit (RSU)

SAFESTRIP road strips are able to perform the following:

- ✓ Embedded static info (i.e. enhanced map data, speed limit, curvature, asphalt characteristics, etc.) to be transmitted to the vehicle, that are programmed after deployment and reprogrammed when the use of the road changes or during road works.
- ✓ Receive dynamic info (i.e. TMC messages), process and transmit them to the passing vehicles, to be offered to the driver/rider in a personalized manner.
- ✓ Measure dynamic environmental parameters (like temperature, humidity, water, ice, oil and smoke) and accurately estimate each vehicle's friction coefficient (through road sensors data fusion with vehicles' intelligent tyres' info).
- ✓ Sense passing vehicles, including non-equipped ones, measure the transit time, speed and lateral position in the lane, provide basic classification of the vehicle type and, thus, offer key road load & circulation data to the TMC.
- ✓ Sense pedestrian crossings, work zones, railway crossings and other critical areas and warn the driver/rider well ahead of them.
- ✓ Enable high accuracy and low cost automatic parking/tolling/insurance policies.
- ✓ Define and manage lane-level virtual corridors for automated driving.

One strip is made of two parts placed adjacent to each other on the road pavement, as shown in Figure 1. The material of the strip is elastic that can bend but not fold. The total height of the construction is 10 mm including the cable and the mounting plates, while the length of each cable is 5m.

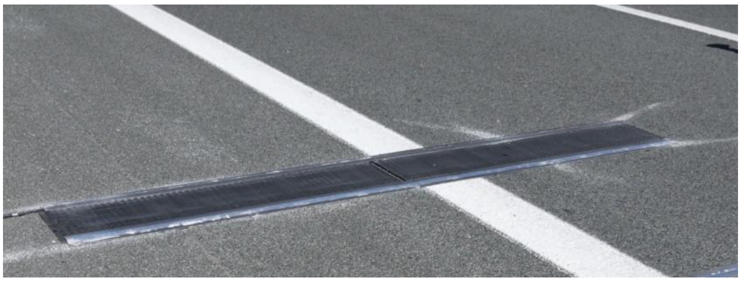

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Figure 1 Installed strip

Assuming that without the SAFE STRIP the fleet has a possible risk of 0.002% of fatal incident, 0.02% of severe incident and 0.03% of bus destroy per year, the benefits below can be calculated:

Table 4: Cost savings related to SAFE STRIP system

Number of shuttles	Monetary benefit from preventing a fatal incident (€)	Monetary benefit from preventing a severe injury (€)	Monetary benefit from preventing the bus destroy (€)	Total monetary benefit per shuttle (€)
1	3.4k	0.34k	5k	9 k

2.3.1.1 Relation of AVENUE system needs and gaps to the SAFESTRIP system

According to Deliverable 2.15 identified needs and gaps of AVENUE system, the following table presents the ones where SAFESTRIP can greatly contribute to:

Table 5: Relation of AVENUE system needs and gaps to the SAFESTRIP system (from D2.15)

Need (code)	Description of the relevant need
Vehicle related	
ON3	Operators wish to reach higher speeds with my AVs, at least 30 km/h, in order for the AV service to be a competitive solution.
	Operators wish a smooth operation of the public transport service with an AV, regardless of the weather conditions and the road behaviour of other vehicles on the road. This requires: • More intelligent sensory systems • Better braking calculation • Better safety zones • Overtaking ability • Closed corridor overtaking
ON16	Operators wish to be able to evaluate new routes remotely based on new map data and existing knowledge
Software related (vehicle software, fleet orchestration)	
ON6	Operators wish the fleet orchestration software to be able to route the vehicles to ensure optimization

2.3.2 Emergency electronic brake light

Emergency electronic brake light warns of a hard braking event in front, especially in case of bad weather conditions. In addition, it enables a vehicle to broadcast a self-generated emergency brake event to the surrounding vehicles.

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Figure 2 EEBL system

Assuming that without the EEBL the fleet has a possible risk of 0.0025% of fatal incident, 0.02% of severe incident and 0.1% of bus destroy per year, the benefits below may occur.

Table 6: Cost savings related to Emergency electronic brake light system.

Number of shuttles	Monetary benefit from preventing a fatal incident (€)	Monetary benefit from preventing a severe injury (€)	Monetary benefit from preventing the bus destroy (€)	Total monetary benefit per shuttle (€)
1	3.7k	0.34k	8k	12k

2.3.3 Emergency vehicle approaching

Emergency Vehicle Approaching communicates with other vehicles, noticing that an emergency vehicle on call is approaching and demands that others give way. [6]

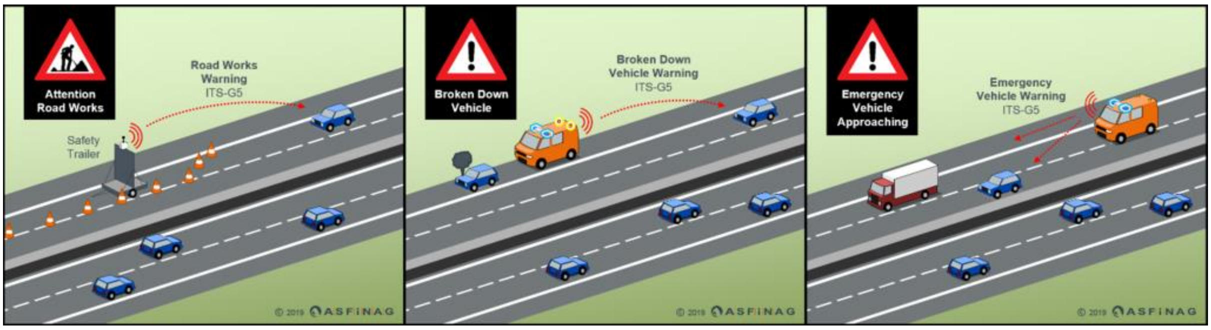

Figure 3 EVA system

Assuming that without the EVA the fleet has a possible risk of 0.002% of fatal incident, 0.02% of severe incident and 0.07% of bus destroy per year, the savings shown below can be expected.

Table 7: Cost savings related to emergency vehicle approaching system.

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Number of shuttles	Monetary benefit from preventing a fatal incident (€)	Monetary benefit from preventing a severe injury (€)	Monetary benefit from preventing the bus destroy (€)	Total monetary benefit per shuttle (€)
1	3.4k	0.34k	7k	11 k

2.3.4 Hazardous location notification

The Hazardous location notification is an important service, since it is used to warn road users about potentially hazardous situations or events on the road. Warnings include information about the location and type of a hazard, distance to the hazard, its expected duration, etc. [8].

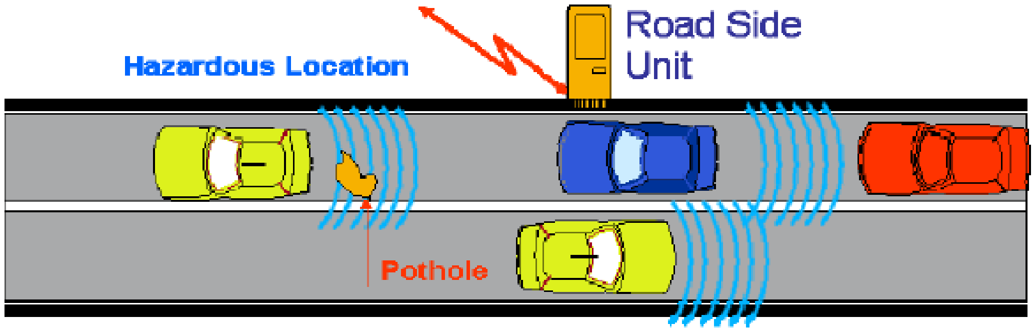

Figure 4 Hazardous location notification service

Assuming that without this service, the fleet has a possible risk of 0.002% of fatal incident, 0.02% of severe incident and 0.07% of bus destroy per year, the monetary benefits can be calculated as following:

Table 8: Cost savings related to Hazardous location notification system

Number of shuttles	Monetary benefit from preventing a fatal incident (€)	Monetary benefit from preventing a severe injury (€)	Monetary benefit from preventing the bus destroy (€)	Total monetary benefit per shuttle (€)
1	3.4k	0.34k	7k	11 k

2.3.5 Slow or stationary vehicle(s) warning

Slow or stationary vehicle warning is a safety-related Cooperative Intelligent Transport System (C-ITS) service that mainly aims to reduce the number of accidents in connection to slow or stationary vehicles, e.g. emergency vehicles and road maintenance vehicles. Slow or stationary vehicle warning contributes to the elimination of traffic jams.

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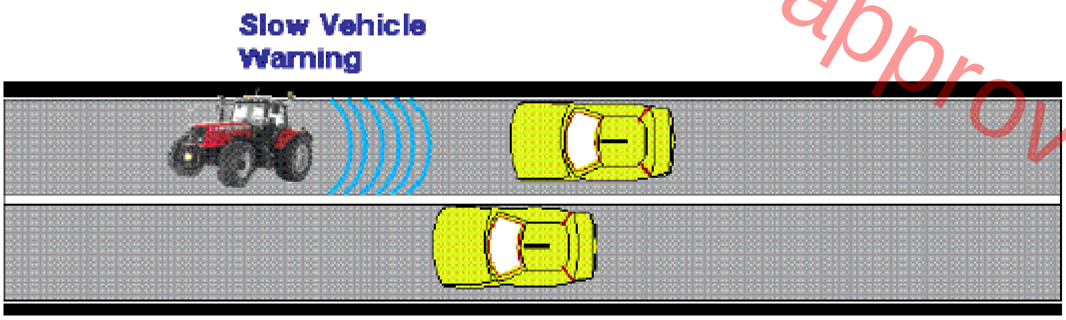

Figure 5 Slow or stationary vehicle warning, C-ITS service

Assuming that without this service, the fleet has a possible risk of 0.002% of fatal incident, 0.02% of severe incident and 0.08% of bus destroy per year, the expected cost savings are shown below:

Table 9: Cost savings related to slow or stationary vehicle(s) warning system

Number of shuttles	Monetary benefit from preventing a fatal incident (€)	Monetary benefit from preventing a severe injury (€)	Monetary benefit from preventing the bus destroy (€)	Total monetary benefit per shuttle (€)
1	3.4k	0.34k	8k	10 k

2.3.6 In-vehicle signage

In-vehicle signage is a V2I based service that informs on relevant road signs in the vehicle's vicinity, alerting the driver/operator to signs that have not been aware of. The main purpose of this service is to provide information and give advance warning of upcoming hazards.

Assuming that without the In-vehicle signage the fleet has a possible risk of 0.002% of fatal incident, 0.02% of severe incident and 0.08% of bus destroy per year, the relevant monetary benefits follow below.

Table 10: Cost savings related to 5 In-vehicle signage system

Number of shuttles	Monetary benefit from preventing a fatal incident (€)	Monetary benefit from preventing a severe injury (€)	Monetary benefit from preventing the bus destroy (€)	Total monetary benefit per shuttle (€)
1	3.4k	0.34k	8k	11 k

2.3.7 Probe vehicle data

The service is to provide vehicle-generated data about vehicles, road conditions and traffic situations to road users, and to road operators (for traffic management) and other types of service providers. In the future the analysis and monitoring of the traffic events will occur by the status messages (CAM – Cooperative Awareness Message) of the vehicles via ETSI G5 communication channel. The ITS Roadside Station (IRS) will receive the Cooperative Awareness Messages and forward them to the ITS Central Station (ICS) to enable a supplement and improvement of the traffic situation analysis, which is achieved with stationary detectors so far. Especially, where the position of the stationary registration are wide apart or rather do

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not exist, these messages can contribute significantly. Building on this, information of travel times and traffic situation can be generated and provided via different communication channels, for example radio or internet.

It could be assumed that without this service the fleet has a possible risk of 0.002% of fatal incident, 0.02% of severe incident and 0.08% of bus destroy per year. Relevant monetary benefits are given below:

Table 11: Cost savings related to Probe vehicle date.

Number of shuttles	Monetary benefit from preventing a fatal incident (€)	Monetary benefit from preventing a severe injury (€)	Monetary benefit from preventing the bus destroy (€)	Total monetary benefit per shuttle (€)
1	3k	0.3k	10k	13k

2.3.8 Green Light Optimal Speed Advisory /Time to Green

Green light optimal speed advisory systems are vehicle-to-everything (V2X) communication applications that transfer signal information between the vehicles and traffic lights, achieving higher time and energy efficiency together with safer traffic at signalized intersections.

Assuming that without this system the fleet has a possible risk of 0.002% of fatal incident, 0.02% of severe incident and 0.06% of bus destroy per year, the benefits below can be expected.

Table 12: Cost savings related to Green Light Optimal Speed Advisory (GLOSA) /Time to Green

Number of shuttles	Monetary benefit from preventing a fatal incident (€)	Monetary benefit from preventing a severe injury (€)	Monetary benefit from preventing the bus destroy (€)	Total monetary benefit per shuttle (€)
1	3.4k	0.34k	6k	10 k

2.3.9 Signal violation/Intersection safety

Signal Violation Warning (SVW) aims to reduce the number and severity of collisions at signalized intersections by warning vehicles who are likely (due to high speed) to violate a red light. Also known as the “Signal violation/Intersection Safety” or “Red Light Violation Warning”.

It could be assumed that without the SVW the fleet has a possible risk of 0.009% of fatal incident, 0.07% of severe incident and 0.1% of bus destroy per year. Based on these values, the expected benefits are:

Table 13: Cost savings related to Signal violation/Intersection safety

Number of shuttles	Monetary benefit from preventing a fatal incident (€)	Monetary benefit from preventing a severe injury (€)	Monetary benefit from preventing the bus destroy (€)	Total monetary benefit per shuttle (€)
1	7k	2k	17k	26k

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2.3.10 Vulnerable road user protection

VRU protection is a warning system for vulnerable road users aiming at the detection of risky situations. This service is designed to increase safety by alerting nearby vehicles on the presence of vulnerable road users (those outside the vehicle such as pedestrians, cyclists).

It can be assumed that without the system, the fleet has a possible risk of 0.01% of fatal incident, 0.9% of severe incident and 0.13% of bus destroy per year. Therefore, the expected cost savings are calculated as follows:

Table 14: Cost savings for vulnerable road user protection system

Number of shuttles	Monetary benefit from preventing a fatal incident (€)	Monetary benefit from preventing a severe injury (€)	Monetary benefit from preventing the bus destroy (€)	Total monetary benefit per shuttle (€)
1	10k	5k	23k	38 k

3 Cost and monetary benefits

The monetary annual benefits both on single shuttle and fleet level are calculated and presented in Table 13 below.

Table 15: Monetary values for the evaluation period, in k€

	FLEET				
Benefits (Monetary) (k€)	**Year1**	**Year2**	**Year3**	**Year4**	**Year 5**
Vehicles	1	1	1	1	1
Emergency electronic brake light	12	12	12	12	12
Emergency vehicle approaching	11	11	11	11	11
Hazardous location notification	11	11	11	11	11
Slow or stationary vehicle(s) warning	10	10	10	10	10
In-vehicle signage	11	11	11	11	11
Probe vehicle data	13	13	13	13	13
Green Light Optimal Speed Advisory (GLOSA) /Time to Green	10	10	10	10	10
Signal violation/Intersection safety	26	26	26	26	26
Vulnerable road user protection	38	38	38	38	38
SAFESTRIP	9	9	9	9	9
Benefit per bus (k€) annually	151,0	151,0	151,0	151,0	151,0
Benefit per new fleet (k€) annually	151,0	151,0	151,0	151,0	151,0
Total fleet per year	1	2	3	4	5
Benefit per whole fleet (k€) annually	151,0	302,0	453,0	604,0	755,0

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The costs for the proposed solutions (per shuttle) are referring to the cost per unit and are presented in table 13. All values are in k€. For the calculations the month rate of 4.5 k€ is used, multiplied by the development and installation effort provided in Table 3. Maintenance and Operational costs have been calculated as described in chapter 2. The life span in most cases is considered to be higher than five years and the replacement cost is integrated into the maintenance cost in order to render the calculations easier to be made.

Table 16: Systems/solutions (cost per bus per solution in k€).

Systems	Total cost per solution (k€)				
	Year1	Year2	Year3	Year4	Year 5
Number of shuttles	1	1	1	1	1
SAFESTRIP	10.5	10.5	10.5	10.5	10.5
Emergency electronic brake light	21.5	21.5	21.5	21.5	21.5
Emergency vehicle approaching	17.5	17.5	17.5	17.5	17.5
Hazardous location notification	17.5	17.5	17.5	17.5	17.5
Slow or stationary vehicle(s) warning	17.5	17.5	17.5	17.5	17.5
In-vehicle signage	17.5	17.5	17.5	17.5	17.5
Probe vehicle data	21.5	21.5	21.5	21.5	21.5
Green Light Optimal Speed Advisory (GLOSA) /Time to Green	17.5	17.5	17.5	17.5	17.5
Signal violation/Intersection safety	47.5	47.5	47.5	47.5	47.5
Vulnerable road user protection	67.5	67.5	67.5	67.5	67.5
Benefit per shuttle (k€) annually	256	256	256	256	256
Benefit per whole fleet (k€) annually	256	512	768	1024	1280

3.1 NPV & IRR

According to the formulas of section 2.2, the Net Present Value and the Internal Rate of Return have been calculated and presented in Table 15. They validate that the investment is going to be profitable for all technical solutions. The NPV is higher for some technical solutions such as ‘‘SAFESTRIP’’ and ‘Vulnerable road user protection’’, while the IRR is higher for ‘‘SAFESTRIP’’ and ‘‘In-vehicle signage’’ systems.

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Table 17: NPV & IRR results for every safety system/ solution

Systems	NPV (k€)	IRR
SAFESTRIP	43,2	3,5
Emergency electronic brake light	7,8	0,2
Emergency vehicle approaching	21,8	0,6
Hazardous location notification	21,8	0,6
Slow or stationary vehicle(s) warning	9,2	0,3
In-vehicle signage	21,8	0,6
Probe vehicle data	20,3	0,5
Green Light Optimal Speed Advisory (GLOSA) /Time to Green	8,1	0,2
Signal violation/Intersection safety	19,5	0,1
Vulnerable road user protection	28,5	0,2

1.2Pay Back Period

The payback period refers to the period that the first vehicle needs to reach the breakeven point, meaning the first investment solely. This happens because the investment should be examined on a yearly basis in order to extract trustworthy results. The maximum payback period is 0.61 years for the system ‘‘Signal violation/Intersection safety’’, meaning that is a bit higher than 7 months. Finally, the payback period is more or less the same for all the systems, i.e. it varies from 4 to 7 months.

Table 18: PayBack Period for all safety systems/ solutions

Systems	Payback period (years)
SAFESTRIP	0,39
Emergency electronic brake light	0,60
Emergency vehicle approaching	0,53
Hazardous location notification	0,53
Slow or stationary vehicle(s) warning	0,58
In-vehicle signage	0,53
Probe vehicle data	0,55
Green Light Optimal Speed Advisory (GLOSA) /Time to Green	0,58
Signal violation/Intersection safety	0,61
Vulnerable road user protection	0,59

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4 Comparisons

The comparative results on NPV and IRR across the different systems are presented in Table 15. The emerging results allow us to understand if the continuous production of a system can be beneficial or not and in which occasion it can be more profitable.

The NPV results were found to be positive for all the solutions; however, the highest price is found for SAFESTRIP that is about 43.2 k€.

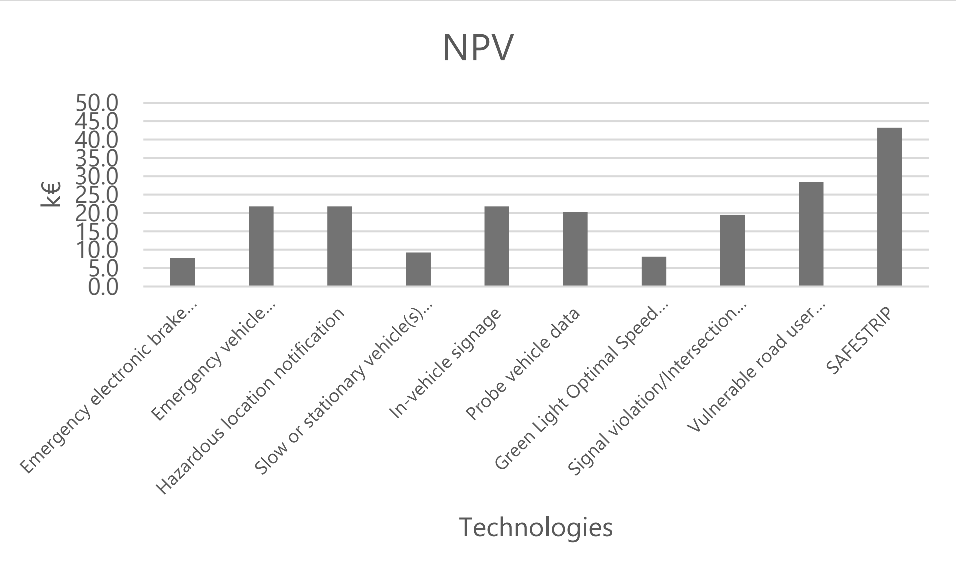

Figure 6 NPV comparative figure for all safety systems/ solutions

Furthermore, the highest IRR among all systems is for SAFESTRIP that is about 3.5. Both NPV and IRR indicate that the investment is profitable for every technical solution.

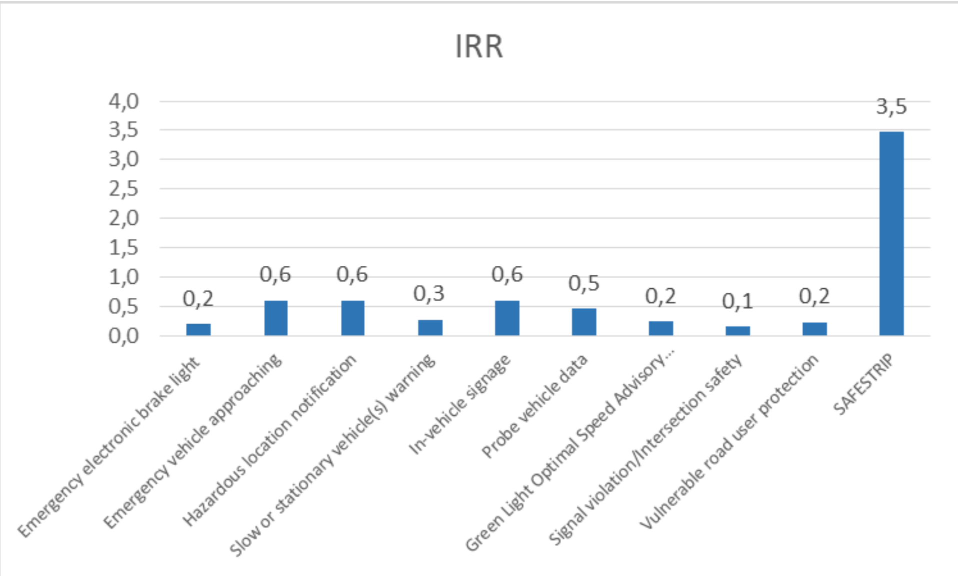

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Figure 7 IRR comparative figure for all safety systems/ solutions

In the payback period the investment was examined on a yearly basis in order to extract reliable results. This means that the AVENUE shuttle investment was considered only for the first year. The payback period was less than 7 months for all the selected solutions. The shortest payback period was noticed for the SAFESTRIP system and it was less than 4 months.

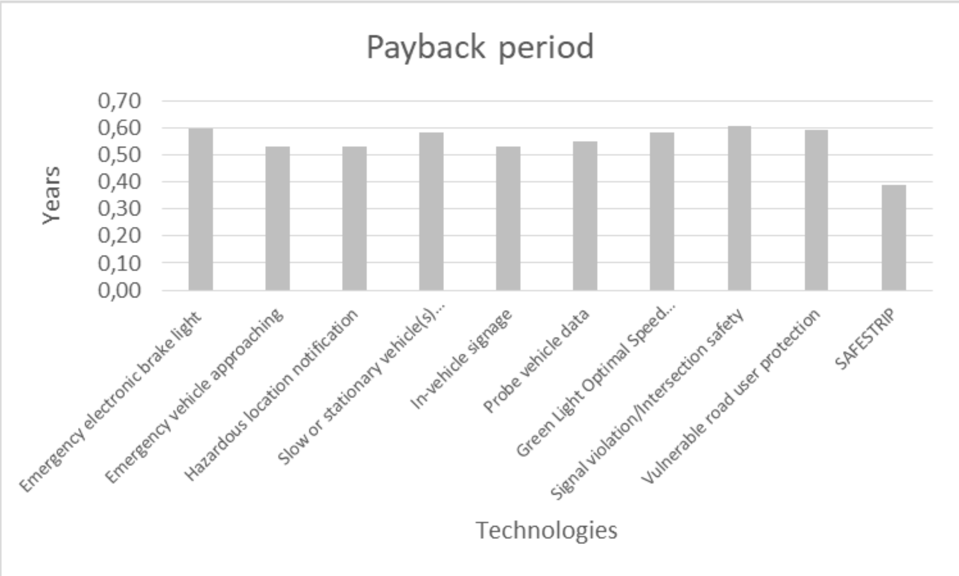

Figure 8 Payback Period - comparative figure for all safety systems/solutions

5 Recommendations for the implementation of SAFESTRIP system to AVENUE demonstrations

Below, recommendations are given for implementing properly SAFESTRIP in the four pilots' demonstrators of AVENUE. According to these, the integration and operation SAFESTRIP is feasible and of reasonable cost since the maximum number of strips per site that need to be placed on the road are 4 and the cost is about 2.35 K€ per unit [9].

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5.1 Number/density of strips proposed per pilot site

It is recommended that one strip should be made of two parts placed adjacent to each other on the road pavement. The material of the strip is recommended to be elastic in order to be able to bend but not fold. The total height of the construction in order to be eligible in all AVENUE pilot sites has to be 10 mm including the cable and the mounting plates, while the length of each cable should be 5m.

It is recommended that the strips should be installed in every crucial spot of the highways (dangerous turn etc.) and generally in every 1 to 1.5 km, depending on the road infrastructure quality. The length of the AVENUE pilot is different among the pilot sites. In case of Lyon the fixed route is 2.6 km which is the maximum among all. In case of Geneva the route is 2.1 km (D7.1). In case of Copenhagen (D7.7), the route length is 1.3 km and for Lux the route is 1.2 km (D7.10) which is the shortest route met in the pilot sites. Thus, the proposed distance between the installed strips varies among the different AVENUE sites.

According to the above recommendations, in case of Geneva pilot site, 3 strips should be used as minimum in order to make the specific technological solution functional. In case of Copenhagen pilot site, the number of strips recommended as minimum is 2. For Lyon pilot site, there should be 4 strips installed, while in Luxembourg the number of strips needed are 2.

5.2 Infrastructure and communication recommendations

The application of C-ITS technologies, specifically SAFESTRIP, covers a wide range of services, various transport situations and involves different actors. To match driver's increasing expectation to receive all information on traffic and safety conditions seamlessly across Europe, a hybrid communication approach is needed, i.e. by combining complementary communication technologies. On vehicle and on infrastructure side, the used C-ITS technologies should be flexible regarding the communication technology, easing the inclusion of future technologies. Since the SAFE STRIP system is modular and the single components follow existing standards, e.g. ETSI TS 102 687 (2018), enhancements are possible.

5.3 Material

For SAFESTRIP, a cold plastic (LIMBOPLAST D480) for rumble strips is the most recommendable material for the main application case (transversal invisible strip on a motorway).

5.3.1 Usage limitations

It is recommended that road markings intended for moving vehicles should be reflectorized if the density of traffic requires and if lighting is poor or there is no lighting.

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5.4 Interoperability Recommendations

Interoperability at all levels is a key element for the success of C-ITS technology, including SAFESTRIP system. The system as a whole needs to be able to interact with autonomous shuttles, and other transport modes at all levels: infrastructure, data, services, applications and networks. Applicable EU-standards, as defined in the standardization mandate M/453 EN (2009), serve to apply deployment specifications. Test procedures should check the interoperability with other "Day 1 C-ITS services" with the aim of creating the conditions for EU-wide interoperability.

Interoperability in case of SAFESTRIP, as recommended, has been ensured in the existing data communication standards. However, interoperability in some special cases, in which no existing standards apply, is recommended to be validated in detail, e.g. regarding other installed infrastructure elements (by the authorities) along the routes.

5.5 Market Introduction

For the final market introduction, it is recommended to follow the C-ITS framework and security policy defined by the European Commission (2017b) based on roles defined in ISO 17427 (2018). This is not a standardization of technology but following the standard on the application framework will likely benefit the implementation.

6 Conclusions

The study has provided useful insights from a technical perspective addressing different aspects related to C-ITS based technologies enhancing road safety in AVENUE demonstrations.

Within this study, the costs of the technologies and sensors, as well as the development and installation effort that provide the baseline for the CBA calculations, have been retrieved from the systems' benchmarking phase and are being presented in their revisited form in this Deliverable. The Fleet Scenario proposed, supports an escalating approach, assuming an initial investment of one shuttle and an additional investment of one shuttle per year, for an evaluation period of 5 years. NPV, IRR and Pay Back Period have been calculated for the ten selected technical solutions.

The internal benefits considered are the ones concerning the OEM/Operator and have been monetarized on the basis of a series of assumptions that are based on literature.

According to the results, both NPV and IRR are positive for every solution. This means that all the selected investments can be considered profitable for the operator. Additionally, the payback period is quite small, as in some cases less than six months are needed in order to reach the breakeven point. Specifically for SAFESTRIP infrastructure-based system, the results show that the NPV is higher than 40 k€ which indicates that the projected earnings generated by the specific technological solution exceed by far the anticipated costs in today's euros. The IRR, which is about 3.5 indicates that the SAFESTRIP solution is a very profitable add-on for the shuttle, since the higher the projected IRR the more net cash the technological solution

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generates for the shuttle's operator. Last but not least, the Payback period for the SAFESTRIP is less than 5 months, which is the shortest period in respect to all other technological solutions. Finally, based on the recommendations for implementing SAFESTRIP in AVENUE demonstration sites, it can be concluded that such a solution is sustainable to be integrated.

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