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Cost Analysis

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Author(s) – in alphabetical order		
Name	**Organisation**	**E-mail**
Dan Langford	UFL	dan.langford@urbanforesight.org
Clive Parsons	UFL	clive.parsons@urbanforesight.org
Emma Clement	UFL	emma.clement@urbanforesight.org
Eriketti Servou	UFL	eriketti.servou@urbanforesight.org

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Abstract
The purpose of this document is to outline the available costs of the ICT4CART solution. Explore the costs, considerations and scalability for each of the ICT4CART use cases and determine their desirability, rate of adoption and likely market sustainability.

Legal Disclaimer

Abbreviations and Acronyms

Term	Definition
AI	Artificial Intelligence
ABS	Anti-lock Braking Systems
AD	Automated Driving
ADS	Automated Driving System
ADAS	Advanced Driver Assistance Systems
AV	Automated Vehicle
CAM	Cooperative Awareness Message
CAV	Connected and Automated Vehicle
CAPEX	Capital expenditures
C-ITS	Cooperative Intelligent Transport Systems
DENM	Decentralised Environmental Notification Message
Dx.y	Deliverable number y that belongs to WPx
EC	European Commission
ETSI	The European Telecommunications Standards Institute
EU	European Union
EV	Electric Vehicle
GA	Grant Agreement
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HD	High Definition
IAM	Identity and Access Management
ICT	Information and Communications Technology
IoT	Internet of Things
IT	Information Technology
ITS	Intelligent Transportation System
IVI	In Vehicle Infotainment
MEC	Multi-access Edge Computing
MNO	Mobile Network Operator
NHO	Neutral Host Operator
OBU	On-board Unit
OEM	Original Equipment Manufacturer
OPEX	Operating expenses
OTA	Over-the-Air
PO	Project Officer
R&D	Research and Development
RO	Road Operator
RSU	Roadside Unit
RTK	Real Time Kinematics
SAE	Society of Automotive Engineers
SOC	Security Operation Centre
TMC	Traffic Management Centre
VRU	Vulnerable Road User
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle to everything (other vehicles and connected infrastructure)

VMS	Variable Message Systems
WP	Work Package

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Executive Summary

The transportation sector has been and will continue to undergo significant disruption for an extended period of time. The convergence of connectivity, computing power, and alternative energy vectors is driving this disruption. It is a time of opportunity, reinvention, and recreation. In only the last few years we have already seen an explosion in investment and accelerated pace of research and development based on the promise of automation. The sector is now in a period of consolidation regaining some balance but the pace of development is only increasing, tempered with some more realistic expectations.

Automation in transportation, related infrastructure and operating environment impacts every other sector of industry and promises seemingly boundless opportunities for innovation, societal benefit, and commercial gain.

The ICT Infrastructure for Connected and Automated Road Transport (ICT4CART) project has been launched to explore how the supporting infrastructure should seek to develop in the coming years and further develop an effective ICT infrastructure for enabling the wide scale roll-out of connected and automated vehicles (CAVs). ICT4CART aims to design, implement and test in real-life conditions a versatile ICT infrastructure for the needs of higher levels of vehicle automation.

It focuses on four high-value use cases: Smart Parking & IoT services, dynamic adaptation of vehicle automation level based on infrastructure information, intersection crossing (urban) & lane merging (highway), and cross-border Interoperability.

ICT4CART Task 8.4 Cost Analysis and Market Sustainability resulted in this report: D8.5 “Cost Analysis”. This report aims to present the available costs of each ICT4CART use case and a model for adoption, market acceptance and sustainability estimating the potential revenues. Complementary details of the business models, including barriers to entry, encompassing the ICT4CART use cases can be found in PU-access deliverable D9.10 “Business Models”.

Section 1, states the task and the audience, Section 2, provides the background and context for the work. Section 3 details the exploration we have undertaken and approach to the research. Section 4, details the cost element that were available. Section 5, explores the customers, potential markets and pricing models for each of the use cases. Finally, Section 6 contains our conclusions regarding the sustainability of the ICT4CART use cases.

1 Introduction

1.1 Purpose

The purpose of this document is to evaluate the costs associated with each of the ICT4CART use cases and provide tools and knowledge enabling the reader to make more accurate cost estimations of deployment at scale. The purpose also includes an evaluation of the market sustainability of each of the ICT4CART use cases. The overall objective is to determine the likelihood that the ICT4CART use cases will be commercially viable and sustainable.

1.2 Target Audience

The initial readership of this deliverable is anticipated to primarily consist of the ICT4CART consortium partners.

As this report aims to provide the tools to help inform those in the CAV technology sector on the potential market sustainability of CAV information services, the information contained will also be pertinent for other organisations situated in sectors involved in the development, deployment and roll-out of CAVs and their supporting infrastructure.

This includes the following categories of organisations:

- Mobile Network Operators.
- Neutral Host Operator.
- Automotive Original Equipment Manufacturers (OEM).
- Information Technology (IT) companies.
- Cybersecurity technology providers.
- Road Network Operators.
- Public Transportation Authorities (local, regional and national).
- Mobility service providers, including public transit operators.
- Policy makers.

2 Background

This section provides an overview of the status of the CAV industry, the ICT4CART project and this sub-task.

2.1 The Connected and Automated Vehicle Industry

2.1.1 Vehicle connectivity

Vehicle connectivity is defined here as the ability for a vehicle or devices within that vehicle to transmit and receive information with other vehicles, systems or users through some means of telecommunications. This has been widespread in some forms for many years now, e.g., real-time traffic information utilised by satellite navigation systems.

Vehicle connectivity can be understood in terms of enabling *information services* to and from vehicles. This is distinguishable from services provided via “traditional” Intelligent Transportation System (ITS), road markings and signage. The “traditional” approach delivers information services through visual communication to drivers and – usually – passive, fixed location detection. On the other hand, the information services delivered through vehicle connectivity are communicated on a machine-to-machine basis and either present information to drivers internally within the vehicle or the information is used automatically by the vehicles on-board systems.

2.1.2 Automated Vehicles

AV technology operates in two dimensions: monitoring the surrounding environment and controlling the position of the vehicle. In more advanced applications, an additional layer of intelligence interfaces with these two functions, allowing the vehicle to make decisions about the motion based on its interpretation of the surrounding environment and curtailing the need for a human driver at all.

In the current road vehicle market, these functions are typically referred to under the umbrella term Advanced Driver Assistance Systems (ADAS). Common examples include:

- Blind-spot cameras.
- Parking assistance, both warnings and automatic manoeuvring.
- Cruise control and adaptive cruise control.
- Anti-lock braking systems (ABS).
- Lane departure warning systems.

The gradual addition of ADAS to new vehicles has been attributed to the demand to improve road safety through the mitigation of human error. As such, this technology is anticipated to continue to develop, likely in the using of additional data sources that are available through mobile connectivity.

Connecting the vehicle to external data sources – such as other vehicles, in-situ proximity infrastructure or a cloud network – adds an additional layer of input to be processed by the on-board systems that support automated driving.

2.1.3 CAVs and their Supporting Infrastructure

The potential for connectivity to improve both vehicle safety, efficiency and the comfort levels of the driving experience is widely recognised across industry, with acceptance from many consumers despite some concerns from change-adverse subsections.

CAVs are Automated Vehicles which have the capability to communicate with infrastructure and other road users. This broadly covers physical (e.g., road signs, road markings, communication infrastructure), and digital infrastructure (e.g., map data, dynamic traffic data) incorporating V2I (Vehicle to Infrastructure) and V2V (Vehicle to Vehicle) communication networks.

The advantages of rolling out connectivity are recognised across the industry, such that the full benefits of AVs can only be realised with this additional capability. Connectivity will underpin CAV functions:

- increased safety will be achieved from better positioning, owing to the V2V information exchange as well as the capability to pinpoint places with hazardous driving conditions;
- increased road efficiency will be delivered from communication with traffic signals, road signs and incident information;
- and driver experience will be improved from a less demanding driving function and data streaming services.

Experts anticipate that fully connected corridors will be established on motorways or urban arterials at the first instance, with a gradual expansion of these connected networks. This would offer fixed route vehicles, such as buses, an opportunity to fully utilise connectivity to improve services.

2.2 The ICT4CART Project

The main goal of the ICT4CART project was to design, implement and test in real-life conditions a versatile ICT infrastructure for the connectivity needs of higher levels of automation, up to SAE Level 4. The project was awarded through the European Commission Horizon 2020 funding program. Like many EU-wide programmes such as CARTRE, C-ROADS and C-MOBILE, the project aims to present a coordinated response to the challenges of the C-ITS strategy.

The ICT4CART project draws on expertise and technologies from across different industries, including telecommunications, ITS, automotive and IT. The consortium is comprised of 21 different organisations working to combine, adapt, and improve technology applications for CAV infrastructure.

The technology solutions underpinning the project was trialled, demonstrated, and validated in four specific use cases. These real-world and challenging environments encompass a range of urban and highway applications with varying degrees of complexity. The project’s test sites are located in Germany, Austria, Italy and the Italy-Austria border.

Secondary outcomes from the project include analysis of the market, business model development, and an open cloud platform. This platform will aggregate data from across the IT environment and provide analytics services. It will be open for integration and exchange to allow third parties to develop and deliver innovative digital services in the CAV space.

The nature of the connectivity architecture and ICT technology that was explored by the consortium is a hybrid configuration of ITS-G5 proximity networks, Mobile Edge Computing (MEC) and mobile networks (LTE and 5G).

2.2.1 “Cost Analysis” task within the ICT4CART project

“Cost Analysis” task, sits within WP8 Evaluation and Impact Assessment. This work package is intended to reconcile the outcomes of ICT4CART’s research, development and testing activities into meaningful results to progress CAV infrastructure.

This task provides the research base on costs, scale, market sizes, and projected investment required to deploy the ICT4CART infrastructure. It comes to a final conclusion on the market likelihood and sustainability of ICT4CART's solution.

The general output architecture of this solution was determined in the "Technical Performance Evaluation" Task 8.2. It will draw on the performance metrics of the various prototype architectures tested in the project to determine the final overall most promising solution(s). This architecture will be the infrastructure that is subject to the cost analysis.

The value that the ICT4CART solution delivers against its intended benefits will be evaluated in Task 8.3 "Impact Assessment". These benefits were defined based on their capability to deliver the use cases defined earlier in the project.

These Use Cases feature connectivity services that are designed to facilitate high-performance vehicle to infrastructure (V2I) connections that enable the speed and detail of data transfer required to inform automated driving tasks.

Each Use Case is with the timeline of intelligent transport services defined in the EU C-ITS strategy, which prioritises "Day 1" Services that have the highest potential for improving road safety and delivering societal benefits[1], and "Day 1.5" Services that are considered mature and highly desirable by the road transport market[2].

Table 1: ICT4CART Use Cases, the test site scenarios and purchasing stakeholder.

No.	Use Case Description	Relevant Scenarios	Beneficiary (as defined in D9.10)
UC1	**Smart Parking & IoT services** Linking the connected vehicle to information about available parking spaces in urban settings.	• SCN1.1: Smart Parking and IoT Services in City of Ulm, Germany* • SCN1.2: Smart Parking and IoT management in City of Verona, Italy	• Drivers/ passengers
UC2	**Dynamic adaptation of vehicle automation level based on infrastructure information** To enable the comfortable and safe automated driving for SAE Level ¾ automated vehicles, the vehicle will receive information from sensors from the road infrastructure (e.g. on traffic density) and make the decision to hand over control to the driver or come to a safe stop.	• SCN2.1: Dynamic clearance, adaptation and handover of vehicle automation level at special conditions in Graz • SCN2.2: Dynamic adaptation of vehicle automation level on Trento motorway • SCN2.3: Dynamic adaptation of vehicle automation level in Verona, Italy*	• Drivers/ passengers • Fleet operators/ vehicle owners • Road network operators
UC3	**Intersection crossing (urban)**	• SCN3.1: Virtual mirror to "see"	• Drivers/

[1] European Transport Safety Council, Briefing: Cooperative Intelligent Transport Systems (C-ITS), November 2017
[2] European Commission, C-ITS Platform Final Report, January 2016

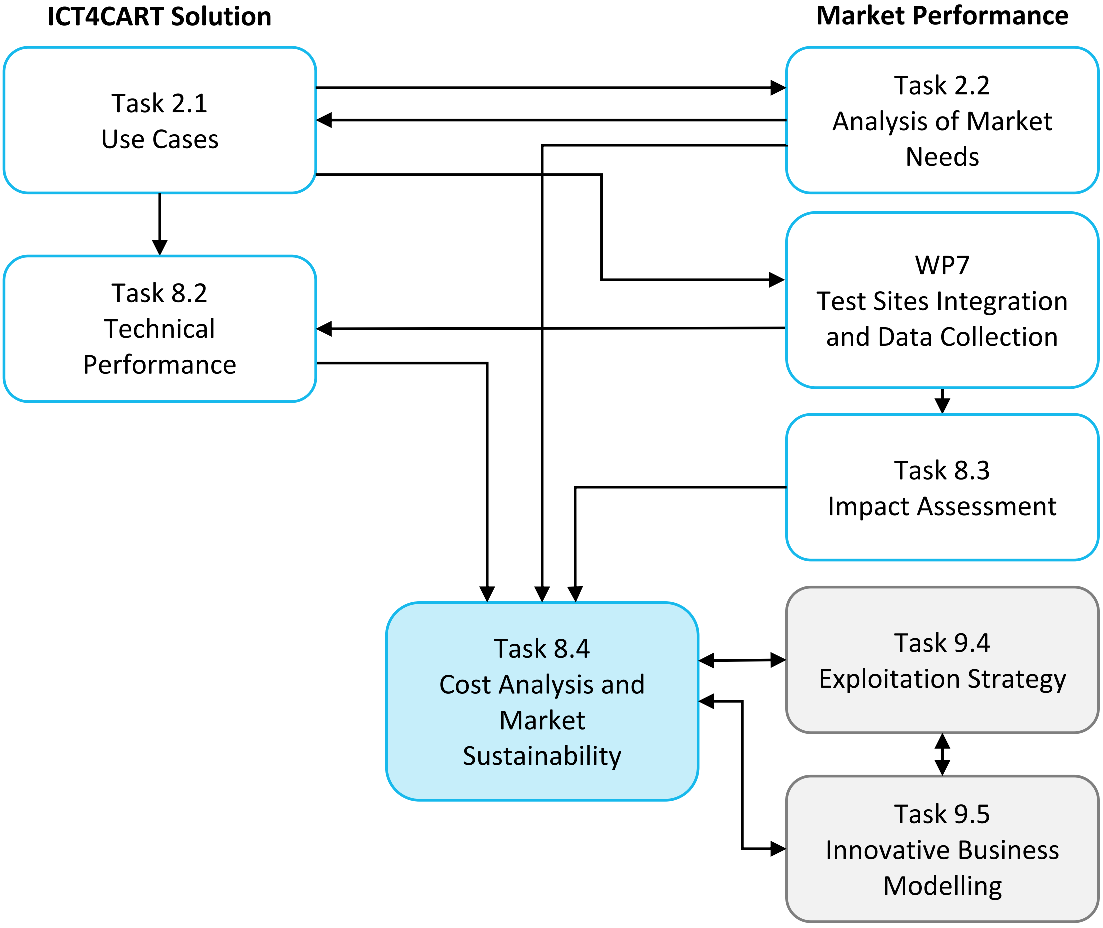
No.	Use Case Description	Relevant Scenarios	Beneficiary (as defined in D9.10)
	& lane merging (highway) – "virtual mirror" Exploiting hybrid connectivity and MEC to create a 360° awareness around the vehicle with very low latency, creating a kind of "virtual mirror" to support the automated vehicle while crossing an intersection or merging into a lane.	surrounding traffic in urban environment. • SCN3.1.a: In City of Ulm, Germany • SCN3.1.b: In City of Verona, Italy • SCN3.2: GLOSA (Green Light Optimized Speed Advisory) in City of Verona, Italy • SCN3.3: Lane merging in Autostrada del Brennero, Italy • SCN3.4 Precise positioning in urban and highway location	passengers • Fleet operators/ vehicle owners • Road network operators • Other road users • Goods recipients
UC4	**Cross border interoperability between Italy-Austria (dynamic adaptation of vehicle automation level) at Brenner border** Test and demonstrate the handover of the vehicle's ITS-G5 network connectivity when crossing the border.	• SCN4.1 Cross border interoperability between Italy-Austria (dynamic adaptation of vehicle automation level) at Brenner border	• AMQP Broker/ Service Cloud Providers

The "Impact Assessment" Task 8.3 will also determine the acceptance of these services and the willingness of end users to pay for their value. These metrics will combine with the costs required to implement the generalised solution to form the ICT4CART cost model.

This cost model will input into a market sustainability analysis, which compares the cost of implementation against the state of the market and concludes on the likelihood of the successful commercial rollout of this solution by various industry actors. It draws on external research and the findings of "Analysis of Market Needs" Task 2.2, which included a research component into the likely future structure of the market.

As "Cost Analysis" works to quantify the investment needed to realise the ICT4CART value propositions, it is closely integrated with two Communication, Dissemination and Exploitation tasks (WP9) that are define the routes to market for the consortium partners (T9.4 "Exploitation Strategy") and potential innovative business models enabled by the solution (T9.5 "Innovative Business Modelling").

Figure 1: Task 8.4's interaction with other ICT4CART work packages and tasks.



2.2.2 Task 8.4 Scope

This task contributes to the overall ICT4CART Project Objective 5: O5. Validate and demonstrate the ICT Infrastructure architecture through the project use cases and test sites.

Figure 4 revisit the architectures of the ICT4CART solution. These will help guide the costing and market sustainability discussions.

Figure 2: ICT4CART High-Level Overview

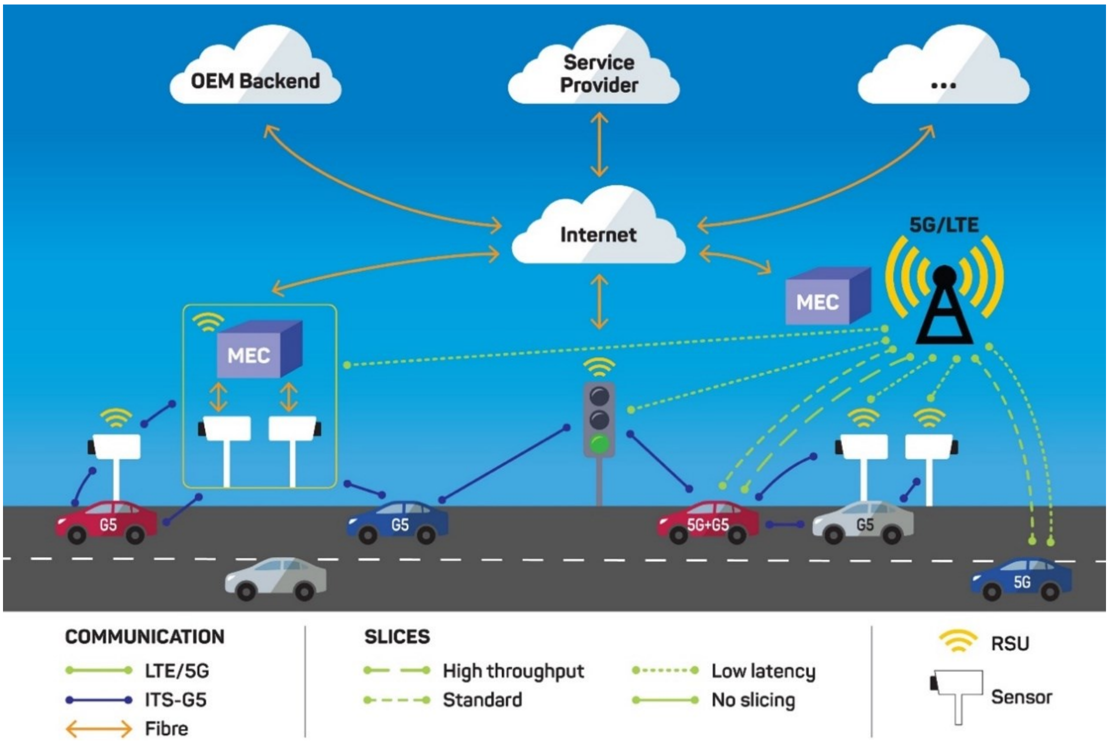


Figure 3: ICT4CART Functional Architecture

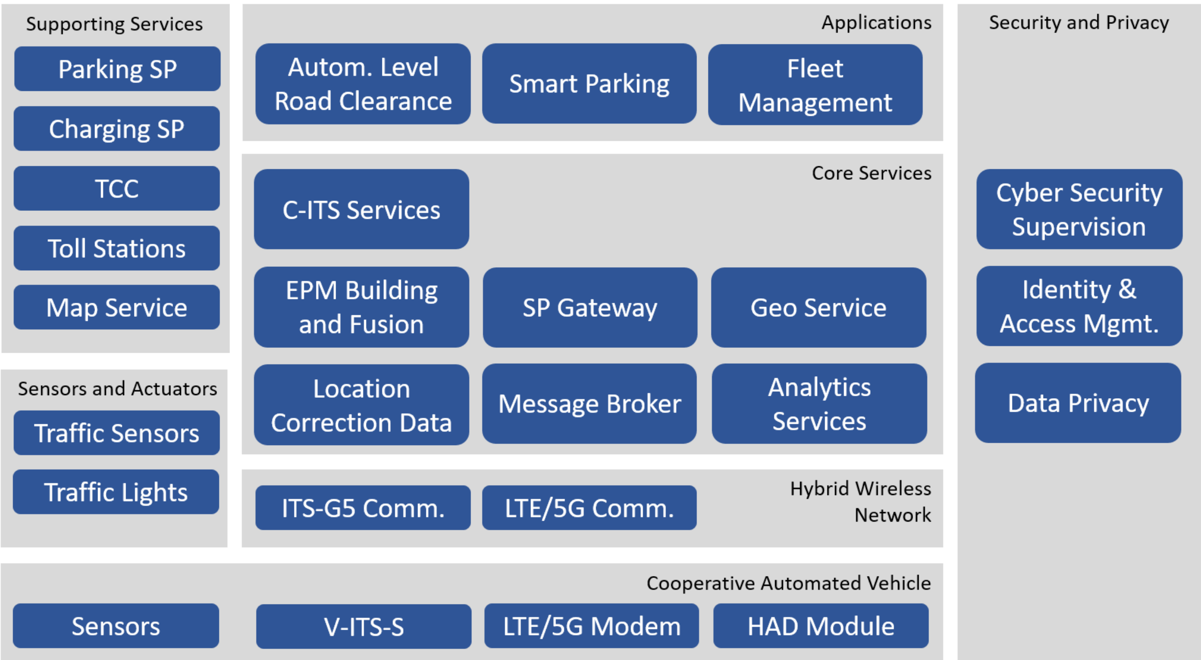
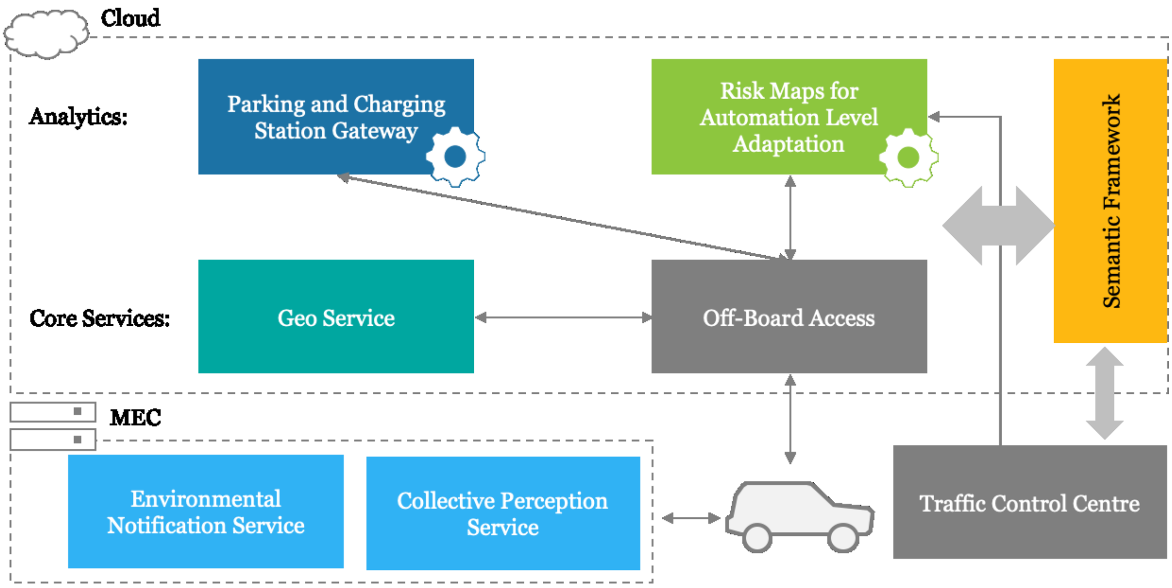


Figure 4: ICT4CART Data/IT Environment



The cost analysis activity in this report will illustrate the validity of the ICT4CART infrastructure architecture for investment and application to the CAV market.

This market, and the needs within it that the architecture is potentially addressing, were defined in the Analysis of Market Needs (PU-access deliverable D2.2) report.

Whereas the Analysis of Market Needs report handled the whole market to define all needs relating to CAV infrastructure and related stakeholders, the cost modelling presented here and subsequent analysis in D9.10 is restricted to the Use Case Scenarios for which the infrastructure has been developed and tested within ICT4CART (see Table 1).

This analysis is also restricted to costing only the investment required for the communications infrastructure, supporting services, deployment and maintenance.

The modelling of the cost of CAVs is limited to the on-board unit (OBU) or Connectivity Control Unit that connects to the infrastructure. This unit connects and communicates via ITS-G5 and cellular networks and is a node in the ICT4CART network architecture.

The unit processes signals from the architecture and transfers them to a central computer, which combines them with signals from the on-board sensors and processes them against the requirements of the journey and the Virtual Mirror before sending resulting directives to the automated driving unit and/or the HMI.

These processes – the signal processing, on-board communication and driving actuation processes – will be unique to the vehicle manufacturer and will not be generalised by the ICT4CART tests. However, the OBU is central to implementing the hybrid connectivity architecture and will need to be costed for full visibility into the market sustainability of this solution.

2.2.3 ICT4CART Work to Date

We have undertaken an initial analysis of the value chains associated with the services identified in this Pu-access Deliverable D2.2 Analysis of Market Needs, i.e., This analysis identifies what value is generated by the services that this infrastructure enables and for whom, and what are the main conceptual steps in generating that value. The idea being that if we can understand the value exchanges involved in each step in the processes that ultimately deliver information to and from vehicles, then we can use this as basis to look into the various ways that this value might be paid for and by whom.

Now that the markets and value are better understood, we then developed value propositions of each service identified and the different business model options associated with generating that value for the customer. This work was the aim of Task 9.5 Business Models.

3 Research Approach and Methodology

3.1 Two-dimensional approach

The research approach for this task was split into two directions that handled the infrastructure architecture and cost in different ways. These directions were defined as two perspectives.

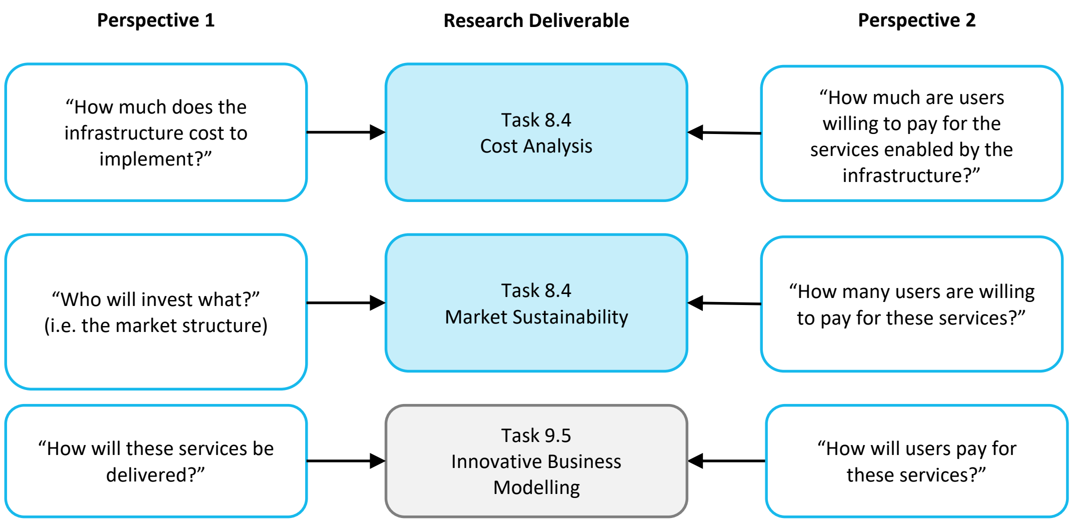
1. "Perspective 1" approaches the cost model from the standpoint of the public and private sector technology and service providers who are implementing the infrastructure.
2. "Perspective 2" approaches the cost model from the standpoint of the end users of the services that the infrastructure delivers.

This two-dimensional approach was necessary because research that focussed on each perspective individually could not illustrate a fully realistic, sustainable and commercially viable cost model. That is, both of these research directions would have resulted in blind spots in the analysis of costs and business models.

Therefore, all research activities relating to the costing could be categorised as answering two key questions: how much does the infrastructure cost, and how much will users pay for it (price). Figure 5 summarises this categorisation and Table 2 lists the research methods used to explore these questions. Understanding the difference between cost and price will help advise the likelihood of market sustainability.

As introduced earlier the cost analysis research is closely integrated with research into the innovative business models that are enabled by this solution (PU-access D9.10). As such, D9.10's research approach had a similar structure; it also references the perspectives defined above and so is included in Figure 5 to demonstrate the relationship between these two research tasks.

Figure 5: Multi-dimensional research approach and how it categorises key questions



3.1.1 Research methodology

Through the course of this research, the activities listed in Table 2 were iterated.

Table 2: A summary of cost modelling research activities by perspective.

Perspective 1		Perspective 2	
	Literature review of wider research		Literature review of wider research
	Survey of Consortium Partners to obtain costs		Definition of ICT4CART's Use Cases
	Interviews with Scenario Leaders		Survey of test participants – Impact assessment
	Survey providers to find what users currently pay for comparable systems in the market.		Analysis of Market Needs Report Including the outcomes of the workshop activity into market structures: which looked at how the market will be structured, i.e. who will pay for what?
	Research the requirements to define cost models based on the unique characteristics of the ICT4CART use cases		Value Mapping activity from D9.10
	Develop tools to enable the construction of cost models		Research providers to find what users currently pay for comparable services in the market.

The results are a combination of numerical findings from the cost modelling research to confirm the sustainable balance of investment for implementation against potential market gains, whilst considering complicating factors including:

Perspective 1

- The structure of the market, and so the investment required by different stakeholders.
- Scale of deployment required.
- Current/forecast investment levels of stakeholders.
- The benefits delivered by each Use Case service.
- Factors potentially hindering the deployment of this solution, including standardisation, legislation, competing solutions, existing contracts and legacy technologies.

Perspective 2

- The willingness to pay of end users, and the projected size of the market.
- Competition such as better alternatives and speed to the market.

3.2 Cost Evaluation and Modelling

The process followed to explore the costs associated with the ICT4CART use cases is:

1. Literature Review.
2. Conduct survey to collate costs from ICT4CART consortium partners.
3. Interview scenario leaders to understand solution dynamics identifying key variables.
4. Survey technology providers to understand how much is paid for comparable systems.
5. Research the requirements to define cost models based on the unique characteristics of the ICT4CART use cases.
6. Research comparable or otherwise equivalent costs that may eb used for evaluation.

3.2.1 Network Layers and Solutions Layers

Utilising the layers described below help us to segment the associated costs. When the costs of these different layers are segmented, it helps with scaling the costs of the entire solution. For example a specific use case may only require one instance of the software solution in the core layer, but may require 10000 instances of the infrastructure listed in the access layer. Table 3 visualised the interaction between the network and solution layers and provided an indication of the pricing that was available during the research.

Some network elements, MEC's in particular, can appear in multiple layers in different implementations due to the range of functions they can potentially perform. An MEC's physical location in the network can also be driven by performance needs such as latency (Owen, 2020).

Table 3: Network and Solution Layers

	Core Layer	Distribution Layer	Access Layer
Software Layer	Applications (Fleet Mgt, Parking Mgt.)	Management Tools (Slicing, AMQP Broker)	Applications (Smart Phone, InCar)
Platform Layer	Cloud (AWS, MS Azure etc.)	MEC's	MEC's
Infrastructure Layer	Data Centers, Servers (RO, OEM)	5G Small Cells, Towers, Fiber	IoT Sensors, RSU, OBU, Vehicles

3.2.1.1 Network Layers

Generally, the network layers are defined functions but can be viewed by the distance from the centre or backbone of the network. The distance can be considered physical distance and/or ping speed (data packet round trip).

Access layer contains devices which are connected to the end devices (Sensors, Smart Phones, Vehicles etc.). The access layer includes terrestrial (e.g. fixed wireless access, mobile access) and non-terrestrial access (e.g. satellite, high-altitude platforms), and represents the boundary of the edge network characterized by radio access.

Distribution layer as the names suggests. Also responsible for network separation through physical and policy application.

Core layer is considered the backbone of the network and the point where networks converge. The core is the location of the IT equipment and function including cloud facilities.

3.2.1.2 Solution Layers

Solution layers presented here are a simplification of the Open Systems Interconnection (OSI) model that is used to abstract the function of telecommunication systems.

Infrastructure is the physical hardware on which platforms and software operate. The infrastructure provides compute, memory, storage and bandwidth resources to the other layers.

Platform is the layer that provides tools, databases, frameworks and other services to support the operation of software.

Software can encompass backend servers through to cloud and smart phone applications.

3.2.2 Software

With modern technology, the integration between and hardware is so close that the division between the two becomes blurred. This trend is also reflected in the costing and is further complicated by the range of business models in the industry.

Hardware is often a capital cost that can be separate from the software which may come with an initial licensing cost. These costs may be distinct from a recurrent software license cost that may or may not include a maintenance cost providing access to software updates and other product enhancements over time.

While we have attempted to separate hardware and software costs when it makes sense and where available, the distinction will often be unclear.

It is common with connected hardware for it to have the capability to receive over the air updates (OTA). OTA is common in telecommunication infrastructure but has started gaining acceptance in the automotive industry. Tesla is he OEM that leads the industry for OTA and is estimated to be 3-5 years ahead of other manufacturers (Taylor, 2020).

3.2.3 Cost Availability

While cost availability was one of many contributing factors that limited the possibility of generating a comprehensive cost model to determine the sustainability of each ICT4CART use case, it was not vital. Although, the availability of cost information was a limiting factor during this activity.

The primary cost that was unavailable was the development cost for core software platforms or management systems. Examples include parking, EV charging, fleet, toll and traffic management systems. The core software platform is a crucial component of an end to end system delivering a CAV Services but the reasons for lack of accurate costing is understandable. They include:

- Commercial sensitivity or general unwillingness to share cost details
- Competitive advantage may be obtained if cost details are disclosed
- Accounting methods may mean that the real cost of development is not known
- Passage of time means the cost of continuous upgrade and modification of features is not tracked
- Transition from R&D to commercial deployment results in the loss of original investment costs (especially when partially funded by grants)

Table 4 provides an overview of which costs were available.

Table 4: Cost Availability

Type	Component	Detail
Communications	LTE/5G (Cellular)	Comprehensive
Communications	ITS G5 (ad hoc)	Comprehensive
Communications	Conventional cabling OR Fibre	Basic
Communications	Multi-Access Edge Computing (MEC) Servers	Comprehensive

Type	Component	Detail
IT Environment	Parking Management Systems	None
IT Environment	EV Charging Management Systems	None
IT Environment	Fleet Management Systems	None
IT Environment	Traffic Management Systems	Partial
IT Environment	Toll Management Systems	None
IT Environment	Map Services	None
IT Environment	Environment Perception Model Building and Fusion	None
IT Environment	Automation Level Road Clearance	None
IT Environment	OEM Systems	None
Infrastructure	VMS Displays - warnings & events	Partial
Infrastructure	Traffic Sensors	Comprehensive
Infrastructure	Video Cameras / Laser Scanners	Basic
Infrastructure	Vehicle detectors (magnetic coils, and depth sensors)	None
Infrastructure	ANPR Cameras	None
Infrastructure	Connected Traffic Lights	Partial
Infrastructure	Parking Sensors	None
Infrastructure	Charging Sensors	None
Infrastructure	Environmental sensors	Comprehensive
Vehicle	Sensors/Cameras	None
Vehicle	LTE/5G Modem	Partial
Vehicle	Vehicle ITS Station (V-ITS-S)	None
Vehicle	Highly Automated Driving Module	None

We anticipate that the different parties interested in exploring the costs of investing in ICT4CART solutions will either already have an idea of some if the costs involved based on their existing business interest or will be able to find obtain accurate cost depending on their specific circumstances. For instance, an MNO will know the accurate cost of provisioning telecommunication infrastructure but may need to obtain IT Environment costs based on the scale of their project. An RNO will know the cost of roadside infrastructure but will need obtain cost of telecommunications depending on scale and whether they build they own or rely on a third party provider.

3.2.4 Shared Infrastructure

The costs involved in the widespread deployment of infrastructure solutions can be significant and will have a material bearing on the affordability of the ICT4CART solution. These costs can vary from zero to many €billions. Key issues to consider when scaling the costs include:

- Some infrastructure components can also be used to provide/support services that go beyond CAVs, for example the provision of communication networks and traffic management systems. Need to determine what proportion (if any) of these costs should be borne by a CAV/ICT4CART solution.
- Options for different "players" to fund major infrastructure components. In the case of telco networks, it is reasonable to assume that the majority of coverage will be derived from private sector investment. However, the infrastructure rollout programmes might still require an element of public sector investment, particularly to ensure universal and simultaneous coverage e.g., sections of road networks not in the proximity of large conurbations.

- There are varying degrees of national infrastructure maturity between different EU countries, which result in significant variations in the additional investments needed to deploy the minimum/required capabilities (to be determined).
- Technology trends may negate the need for some infrastructure components required by the current ICT4CART deployments. Of note is the issue of traffic management systems. Vehicles will be capable of gathering and sharing a wide range data drawn from on-board sensors. In future it may, therefore, be possible to avoid the need to deploy large arrays of new roadside sensors and cameras.

3.2.5 Cost "Ownership" and Sustainability

If the ultimate objective of task 8.4 is to enable the reader to identify whether an ICT4CART solution is commercially or economically sustainable, it will be essential to identify the extent to which a variety of different parties will bear the various investment and running costs. Similarly, critical to this analysis is determining and allocating the expected benefits to be derived from an ICT4CART solution (accident reductions, reduced transport costs, etc.).
Key interested parties for this analysis include:

- National and/or local government bodies;
- Road network operators (national and/or local);
- Private sector infrastructure providers e.g., telcos;
- Smart and internet service providers;
- Vehicle manufacturers and/or commercial fleet operators;
- Private motorists;
- Other industry related organisations e.g., insurance companies.

3.3 Market Sustainability

The following research activity outlines the steps taken to reach a final conclusion on the market likelihood and sustainability of the ICT4CART solution.

1. Understanding the Customer.
2. Benefit to the Customer.
3. Understanding the Market.
4. SCN Specific Considerations.
5. Pricing.
6. Comparable Markets.
7. Pricing Models.
8. Potential ICT4CART Pricing.
9. Challenges and Dependencies.
10. Sustainability Discussion.

3.4 Adoption Models

In order to both be able to count the number of customers for each ICT4CART use case and scale the required telecommunication network we need to understand how quickly the technology is being adopted in the market.

The adoption model can be used to:

- Quantify the users of Smart Parking both in-vehicle (OEM integration) and on smartphones. The adoption model can be applied to all smartphone owners but only new vehicles. The reason for the difference on the application of the adoption model is due to the fact that smartphones allow the instant addition of new applications where (OTA) application updates in vehicles is relatively new with limited market penetration.

- Quantify the rate of integration of Dynamic Adaption technology into new vehicles by OEM's. Similar to Smart Parking the adoption model should be applied model to new vehicles. An aftermarket for V2X solutions will arise to retrofit existing vehicles but currently, it requires significant integration efforts (Brandmotion, 2020).

- Quantify the customers of Virtual Mirror both in-vehicle (OEM integration) and on smartphones. The adoption model can only be applied to new vehicles. While much reduced version of this use case may come available on smartphones, the real benefits will be realised by OEM integration. As with Dynamic Adaptation, a retrofit aftermarket will develop.

- Quantify the rate of integration of Cross Border technology into new vehicles by OEM's. In this use case can be applied to new vehicle sales similar to all of the above use cases.

For this report we are using the Bass diffusion model to estimate technology adoption. The results can be used to understand market adoption to estimate both infrastructure requirements and potential market adoption, and therefore sustainability.

3.4.1 The Bass diffusion model

Unlike other technology adoption models (including the Gompertz curve that was used in the Ghent cost model that inspired our overall model) the Bass diffusion model accounts for network effects and early adopters. The Bass model was specifically developed to model the adoption of new products with the assumption that "the probability of purchase at any time is related linearly to the number of previous buyers" (Lartey, 2020).

Network effects and early adopters will be prominent in CAV technology adoption, as different vehicle markets, fleet operators, and functions, adopt connectivity and their enabled functions en masse. For example, car sharing services may be early adopters of smart parking services, using them across their fleet, and in time this function will be adopted by other road transport users, the imitators.

3.4.2 Bass model coefficients

This model is based on three coefficients M, p and q, described in the table below, and produces a time-based number of adopters.

Table 5: Generalised coefficients used in the Bass Diffusion model.

Coefficient	Description
M	The ultimate market potential. This is the potential number of adopters of the new product.
p	The coefficient of innovation, external influence, or advertising effect. This captures the "innovators" subset of consumers who will adopt the product due to external influences.

q	The coefficient of imitation, internal influence, or word of mouth effect. This captures the behaviour of those “imitator” consumers for whom network effects and the purchasing decisions of others are an important influence in their purchasing decisions.

3.4.3 Forecasting using the model

In forecasting the adoption of a new product introduction, these parameters are altered to reflect different scenarios. They are estimated based on judgements on how contagious the product’s adoption will be and the ultimate market potential.

This method of guessing by analogy using typical numbers for coefficients p and q, and algebraic permutations of them, has proven successful in producing forecasts for adoption rates that are consistent with historical data for analogous products (Mahajan, Muller, & Bass, 1995).

Forecasts produced using the Bass diffusion model may not be entirely accurate, but they have proved consistent and realistic enough to provide a feasible indication of adoption rates that are suitable for our cost modelling purposes.

3.4.4 Application to ICT4CART’s technology

Our cost modelling activity has applied the Bass diffusion model to vehicles in Europe. For each use case and market scenario, the coefficients of innovation (p) and imitation (q) were altered to reflect assumptions about consumer behaviours based on the use case technology and market scenarios, and how they affect the desirability, willingness to adopt, and strength of network effects that influence purchasing decisions. The application to the vehicles in Europe can be found in Annex 2 - Technology Adoption Rates.

In CAV technology spaces, the purchasing decision and transaction are not necessarily completed by the individual end user of the technology. For example, logistics fleet managers may choose to install connectivity in their fleet, or insurance companies may mandate a degree of connectivity in all vehicles that they cover. Both of these examples do not require the driver/passenger of the individual vehicle to make a value-for-money decision.

However, the benefit of this decision ultimately distils in the experience that the driver has using their vehicle. As such, this analysis has simplified the value chain to assume that the purchase decision maker and the purchaser can be modelled as the individual vehicles on the road.

3.4.5 The ultimate market potential (M)

The ultimate market potential has been modelled as the number of new vehicles purchased after the launch of the technology in Year 0 of our analysis, 2022.

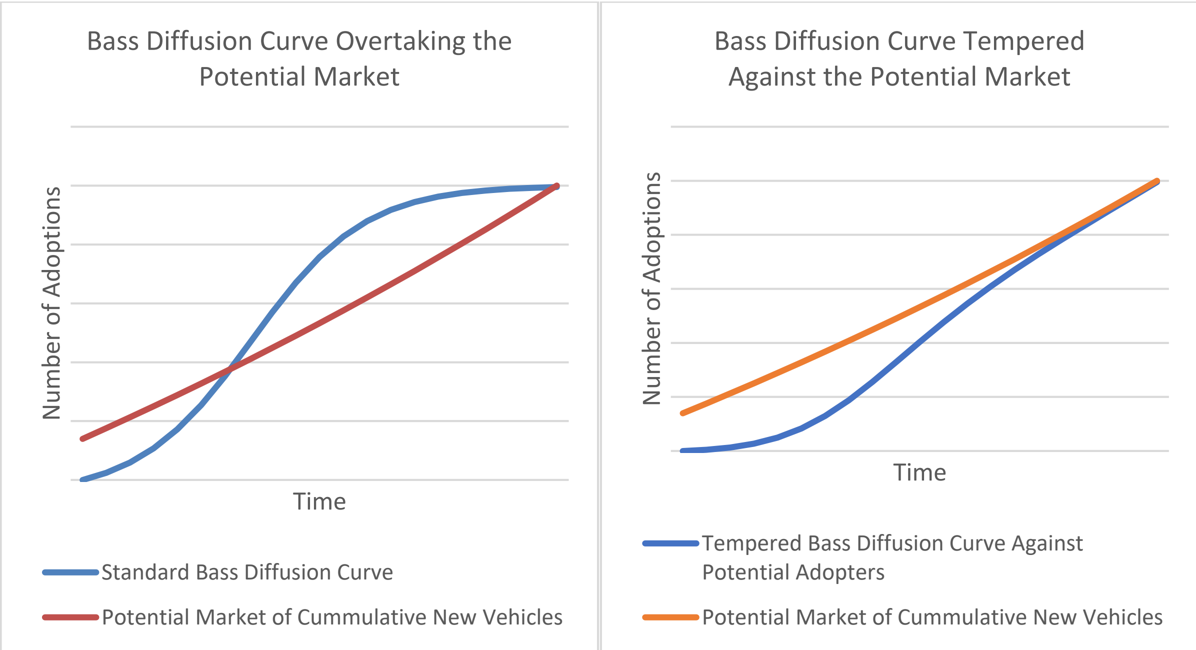
The assumptions that have been made to reach this variable are:

- The technology will not be retrofitted onto existing vehicles, or utilized via add-on equipment, and therefore its adoption is limited to the uptake of new vehicles.
- The number of new vehicles has been projected using the proportion of new vehicles in use in the European Union only from 2018 to 2019 (European Automobile Manufacturers Association, 2021).

- The rate of road vehicle sales and scrappage is assumed to remain consistent at the 2019 rate of 5.26% and 3.53% per annum, respectively. Though historically, the rate of growth has increased year on year, this approximation has been made to account for two factors:
    1. The disruption to the car industry and sales of news cars as a result of the Covid-19 pandemic (Brockmeier, Furcher, Köstring, & Lühr, 2020).
    2. Forecasts that car ownership rates will reduce across Europe as new models of ownership and mobility services, including ride hailing and car sharing, grow in popularity (Deloitte, 2017).

M is applied to represent a fixed population (for example, households) that is available to purchase a new technology. However, in this model, M increases year-on-year with the number of new vehicle purchases. Because of this, the "S" of a Bass curve results in the population of adopters (NA) overtaking the number of potential vehicles (i.e. new vehicles) at some time points. Therefore, this modelling activity has applied the Bass S-curve number of adopters as a proportion of all new vehicle sales, in order to temper it against the linear growth of M.

Figure 6: Tempering the Bass Diffusion curve against the potential market.



3.4.6 The coefficients of innovation and imitation (p and q)

These coefficients represent the influences at play in the purchasing decision and affect the rate at which a new technology diffuses through the whole population.
In this application, they are used to reflect the scenario under consideration and are estimated to reflect:

1. The desirability of the Use Case technology in the target market (p).
2. The extent of the barriers or incentives for adoption, which is a result of the market structure (q).

The p and q coefficients have each been allocated a high, medium and low nominal based on the averages for these figures and the coefficients used in the analysis of the uptake of Electric Vehicles in different scenarios by Becker et al (Becker & Sidhu, 2009).

Table 6: The nominal p and q coefficients are allocated based on expert judgements.

Coefficient	Low	Medium	High
p	0.01	0.02	0.025
q	0.3	0.4	0.5

Both coefficients are defined for each use case, and each market structure. This then allows for analysis and conclusions to be drawn into the appropriate market structure to introduce this technology at an appropriate cost.

The p coefficient uses the rankings of the desirability of different connected auto technologies from a UK survey (Bornstein, Rakow, & Clemente, 2017). This desirability is set at low, medium, or high for each Use Case based on their position in these rankings.

The q coefficient is estimated using a judgement on the external influences on adoptions based on barriers and incentives to purchase the Use Case technology. To reach this judgement, the following questions were considered:

- How different is it to the current norm?
- How significant are the network effects?
- Will people automatically adopt the service when purchasing/leasing a new vehicle?
- Are there costs of adoption? Or other barriers?

For understanding market sustainability, our adoption model provides a guide for the rate at which the ICT4CART use cases will penetrate the market, suggesting maximum potential revenues over time. This could be considered the Serviceable Available Market (SAM), describing the portion of the Total Addressable Market (TAM) that ICT4CART use cases will target.

For costing purposes, our adoption model will primarily be applied to different calculations that aim to understand the proportion of vehicles adopting the ICT4CRAT use case technologies. This will enable the calculation of cost elements such as bandwidth requirements, explored in the following section.

3.5 Vehicle Density

Connected vehicles are the user equipment that is connected to the radio network, effectively smartphones on wheels. We need to understand the density of vehicles to determine the infrastructure required to service a cost-effective proportion of vehicles while providing a useful solution.

In this section, we will detail a process for determining the bandwidth required for CAV's based on multiple variables. The reader will be able to apply this process to their own exploration of costs at the scale of interest using relevant "ground truth" data.

Intersection density and peak vehicle density are two variables that guide the infrastructure needed to support the ICT4CART solution. These variables are highly influenced by the local physical environment and conditions, and as such we are using a generalised measure. When applying this model with any specific location, these input variables must take into consideration the real-world environment. Ideally the reader will be able to identify and utilise actual figures collected at the subject location.

The maximum vehicle density will help advise how much network bandwidth will be required in a given area. The area will most likely be either a square kilometre or a radius based on 4G LTE base stations or 5G small cells.

Figure 7: Types of Small Cell Tower

Type of Small Cell	Coverage Radius	Indoor Outdoor	Transmit Power	Number of Users	Backhaul Type	Cost
Femtocells	30 - 165 ft 10 - 50 m	Indoor	100 mW 20 dBm	8 - 16	Wired, Fiber	Low
Picocells	330 - 820 ft 100 - 250 m	Indoor Outdoor	250 mW 24 dBm	32 - 64	Wired, Fiber	Low
Microcells	1600 - 8000 ft 500 - 2500 m	Outdoor	2000 - 5000 mW 33 - 37 dBm	200	Wired, Fiber, Microwave	Medium

Source: (Khan, 2020)

In turn, vehicle density is defined by the speed and the headway required for vehicles can safely traverse a particular segment of roadway.

The speed at which vehicles can safely traverse a particular segment of roadway is influenced by many factors but a major factor is the intention of the roadway design. Roadway design and their resulting classification traditionally is a contrast between speed and accessibility. More modern thinking considers road classification as a contrast between movement and place.

The functional classification of a roadway can differ widely between countries and regions and can include 6 or more classifications (Bartlett, 2013). For simplicity in this study we are using three (3) broad categories and their respective common speed limits across Europe (AA Ireland, n.d.) as shown in Table 7.

Table 7: Roadway Functional Classification and Speed

Functional System	Services Provided	Speed
Primary, Arterial or freeway / motorway	Provides the highest level of service at the greatest speed for the longest uninterrupted distance, with some degree of access control. Connects municipalities and states.	110 km/h, 70 mph
Secondary, Collector or Distributor	Provides a less highly developed level of service at a lower speed for shorter distances by collecting traffic from local roads and connecting them with arterials. Connecting municipalities to the next level of the network.	80 km/h, 50 mph
Tertiary, Local, or local and	Consists of all roads not defined as arterials or collectors; primarily provides access to land with little or no through	50 km/h, 30 mph

Functional System	Services Provided	Speed
rural	movement. Connecting small towns, villages and communities within municipalities.	

At this point we need to incorporate the concept of 'passenger car unit' (PCU) is used to convert all types of traffic into an equivalent number of passenger cars (National Academies of Sciences, Engineering, and Medicine, 2022).

The PCU and minimum safe headway calculations can be impacted by many variables and should be validated locally before application. Variables include driver characteristics, weather conditions, roadway shoulder and lane width but traffic engineering is beyond the scope of this report.

Table 8: Passenger Car Unit (PCU) values for various vehicle types

Vehicle Type	PCU Value
Pedal Cycle	0.2
Motor Cycle	0.4
Passenger Car	1.0
Light Goods Vehicle (LGV)	1.0
Medium Goods Vehicle (LGV)	1.5
Buses and Coaches	2.0
Heavy Goods Vehicle (LGV)	2.3
Articulated Buses	3.2

The United Kingdom Highway Code (rule 126) states that all drivers "should allow at least a two-second gap between you and the vehicle in front on roads carrying faster-moving traffic" (UK Department for Transport, 2015). We will use a 2-second headway as the minimum safe driving distance and an average vehicle length of 4.4 meters for calculating the density of vehicles.

It is worth noting that headway does have a significant impact on ridership (Ceder, 2007). This may be relevant to readers for a number of reasons. Increased ridership may equate to more mobile devices being present within a specific area during a specific period of time, resulting in increased bandwidth utilisation. Headway is also a variable that benefits from vehicle automation and platooning technology, especially when applied to mass transit.

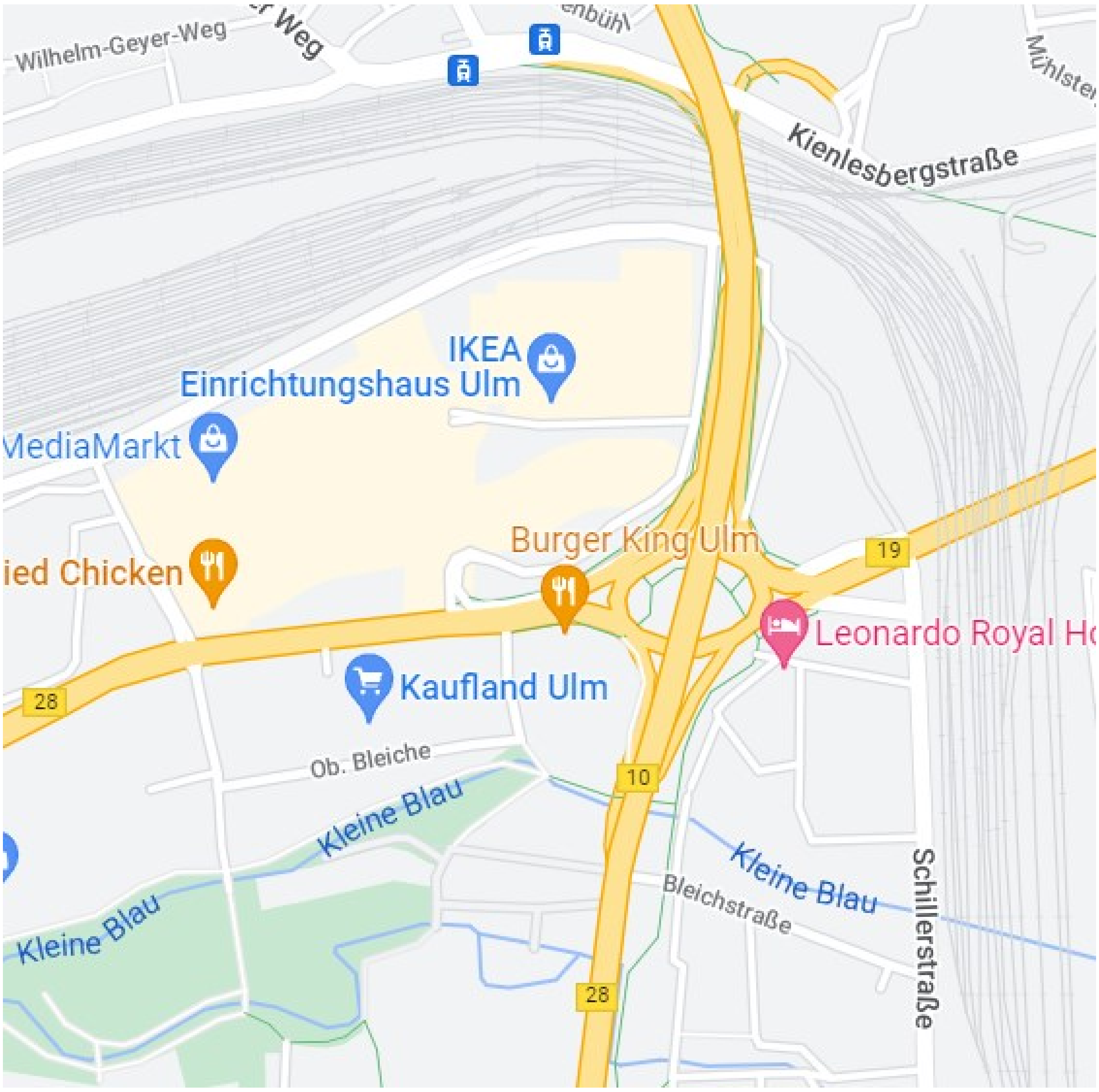
Each of the road classifications and respective speeds, results in the theoretical maximum linear PCU density in Table 9.

Table 9: PCU per kilometre

Road Classification	PCU per linear lane kilometre
Primary (110 km/h, 70 mph)	15.26
Secondary (80 km/h, 50 mph)	20.47
Tertiary (50 km/h, 30 mph)	31.08

Considering Figure 8: 1 km^2 of Ulm Germany Figure 8, which represents one km^2 of Ulm in Germany, the major roadway in this figure is roughly 2.04 km in length and has four lanes. For simplicity, we are not considering turning lanes and the roundabout. The resulting PCU density calculation and result is in Table 10.

Figure 8: 1 km^2 of Ulm Germany



Source: Google Maps

Table 10: PCU per kilometre in Ulm Germany

Road Classification	Calculation	PCU Density
Secondary (80 km/h, 50 mph)	PCU/km x Lanes x Distance 20.47 x 8 x 2.04	334 Vehicles

The next step would be to apply an adoption curve to identify what proportion of the vehicle will be using the ICT4CART use case of interest.

Knowing this peak density of vehicles and an area of interest then enables further analysis. Other variables that may be considered for this type of calculation may include:

- Number of lanes.
- Road density (or lane kilometres) within a specified area.
- Intersection density and impact on PCU density.

There is research that suggests that ITS-G5 would outperform C-V2X where the density is over 150 vehicles/km^2 (Mannoni, Berg, Sesia, & Perraud, 2019)

Next we will seek to understand the range of data volumes that can be generated by connected vehicles in an area, then we can consider the performance requirements of the infrastructure.

3.5.1 Data Volume, Bandwidth and Latency

To understand the peak data volumes and bandwidth required in an area we take the PCU density and apply the adoption model to learn the density of connected vehicles with a particular ICT4CART CAV Service. Knowing the density of vehicles using the CAV Service of interest in a specific area will enable an exploration of data volume, bandwidth and latency requirements.

While data volume does add to the cost of any connectivity solution, we will not be considering it in this report. What is more important is the cost of the infrastructure required to support the peak bandwidth demanded by users, especially for the safety related CAV Services. Peak bandwidth is the maximum probable bandwidth requirement needed is all vehicles in an area access CAV Services being explored at the same time. Bandwidth requirements are needed to scale the network appropriately and in turn calculate the cost of telecommunication CAPEX and OPEX.

Table 11: Bandwidth Requirement for use casesTable 11, provides examples of data volume and bandwidth requirements for different C-V2X use cases and identifies the closely related ICT4CART use cases (5G Automotive Association, 2020). These estimates can be used to calculate the peak bandwidth requirements for any situation being investigated.

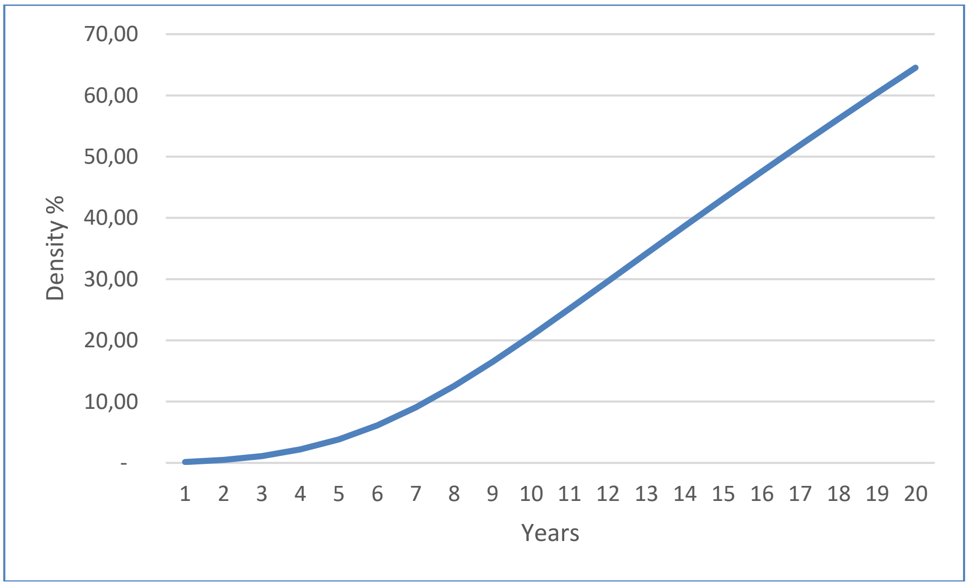
Table 11: Bandwidth Requirement for use cases

ICT4CART Use Case	Use Case	Upload	Download	Latency (ms)
Smart Parking	NA	Negligible	Negligible	NA
Dynamic Adaptation	Remote Automated Driving Cancellation	300 bytes	300 bytes	100
Dynamic Adaptation	High-Definition Map Collecting and Sharing	47 Mbps	16 Mbps	100
Dynamic Adaptation	Infrastructure Assisted Environment Perception		4 Mbps	100
Virtual Mirror	Automated Intersection Crossing	450 bytes	1500 bytes + 450 bytes per vehicle	10
Virtual Mirror	Cooperative Lane Merge	300 bytes	300 bytes	20
Virtual Mirror	Cooperative Manoeuvres of Autonomous Vehicles for Emergency Situations		48 Kbps	10
Virtual Mirror	Coordinated, Cooperative Driving Manoeuvre		64 Mbps	40
Cross Border	NA	Negligible	Negligible	NA

Extreme use case comparison	In-Vehicle Entertainment (IVE) - High-Definition Content Delivery, On-line Gaming and Virtual Reality		50 Mbps - 250 Mbps / stream	

Based on the Ulm example above we can apply the adoption model in Figure 9 to find that in 2030 (year 10) 20% or 67 of the vehicles in that 1 km^2 have a Smart Parking solution installed. Other mobile devices such as smartphones will likely have a much faster adoption rate of Smart Parking solutions.

Figure 9: Density of Smart Parking in the European Fleet over time



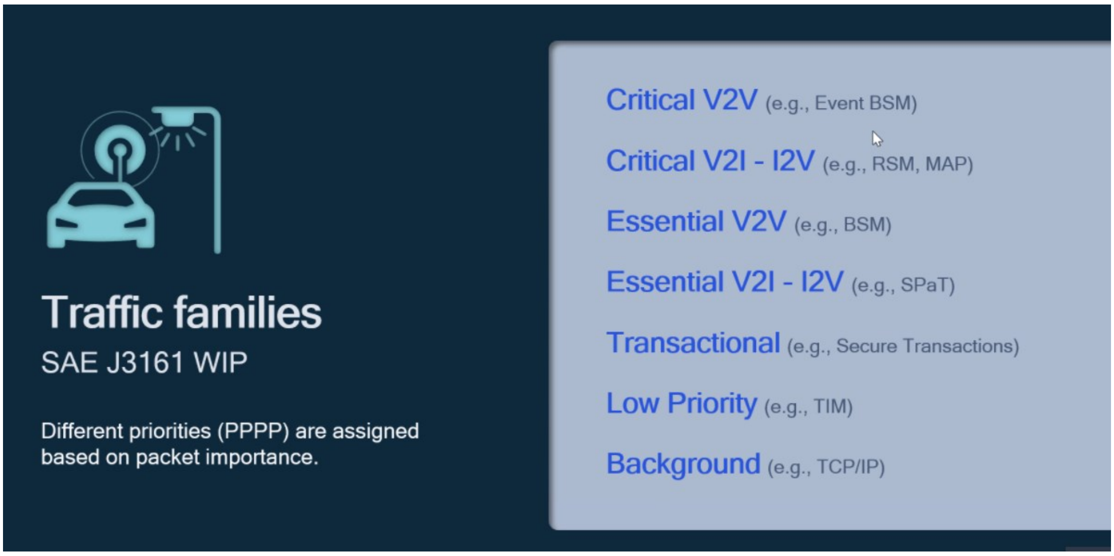
Again using the one km^2 explored in Table 10 above we can use the PCU Density to estimate the peak bandwidth requirements. In this case we will use the bandwidth needed for "High-Definition Map Collecting and Sharing" from Table 11. This use case is a good proxy for the Dynamic Adaption ICT4CART use case and Table 12 shows the resulting estimated peak bandwidth requirement for the network supporting the 67 CV's that could potentially be located in one km^2 in Ulm Germany.

Table 12: Dynamic Adaption Peak bandwidth in Ulm Germany

PCU Density	Calculation	Peak Bandwidth
67 Vehicles	PCU/km x Bandwidth 67 x 47 Mbps	3,149 Mbps

One technology that can help manage the quality of service and utilisation of the available network is traffic prioritization and resource reservation. Prioritisation of the network is critical to the successfully deployment of safety related use cases. This report will not explore this topic in detail but it is an SAE Work in Progress (J3161) as shown in Figure 10.

Figure 10: SAE J3163 WIP



Source: Jim Misener (Qualcomm)

Latency is another factor that is critical to safety related and other V2X use cases. Latency defines the proximity/location and in turn density of MEC Servers and therefore cost and price (lower latency equals higher price). Although, latency can also be determined by traffic prioritization if physical proximity isn't a limiting factor.

3.6 Intersection Density

In addition to the proportion of vehicles that will adopt the ICT4CART use cases which is explored in section 3.4 Adoption Models, knowing the density of intersection is also a key variable involved in calculating costs.

Unfortunately, there is less definition and reasoning behind the density of intersections compared to the functional classification of roadways. The level of organisation in city can be dependent on the age of the city and is influenced by its growth over time. Newer urban areas for example tend to be more organised and less organic with a regular road layout resulting in consistent intersection density.

Development of cost models for ICT4CART use cases, such as Virtual Mirror can be very dependent on intersection density. Intersections can be a point of vehicle concentration, host numerous sensors, RSU's and a logical location for MECs and LTE/5G base stations.

Intersections are also prone to heavy concentration of vulnerable road users and is a major source of serious injuries and fatalities. In the United States, more than 50 percent of the combined total of fatal and injury crashes occur at or near intersections (Federal Highways Administration, 2021) and in Europe 43% of all road injuries occur at intersections (Simon, Hermitte, & Page, 2009).

For these reasons, the utilisation of CAV Services and the volume of data requested from the network will be greatest when approaching and traversing intersections.

Vehicle volume can suggest whether an intersection is signalised or not which will help us to understand signalised intersection density. Other factors that contribute to the decision to signalise an intersection includes the volume of crashes. Signalised intersections are favoured for the deployment of infrastructure as power and fibre or wired telecommunications is often readily available.

ICT4CART partner Ulm University provides a good example of the amount of infrastructure that can be deployed in an unsignalized intersection in Figure 11.

Figure 11: Intelligent infrastructure sensors on a public junction in Ulm-Lehr

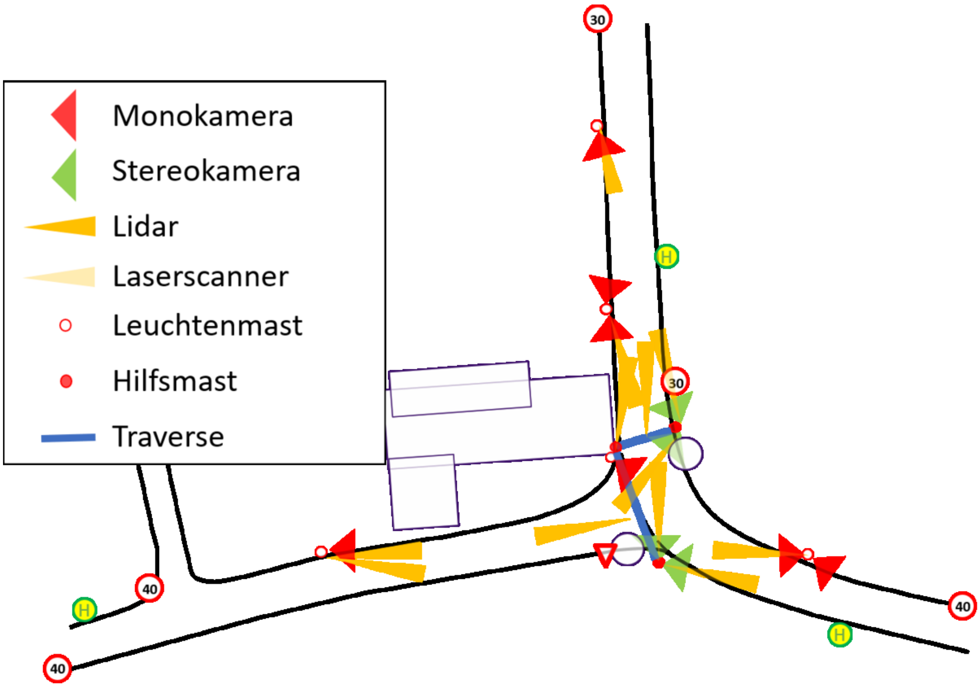


Table 13: Example costs for an unsignalised intelligent intersection

Description	Number	Total Cost
8 cameras	8	€6400.00
4 pairs of stereo cameras	4	€4400.00
8 LiDAR sensors	8	€7200.00
4 laser scanners	4	€7600.00
5 light poles		NA
2 auxiliary traverses		NA
Sensor Processing Units (to MEC via LTE/5G)	3	€1500.00
Multi-Access Edge Computing (MEC) server		€5000.00
ITS-G5 Adhoc network (RSU's etc.)	3	€8700.00

Knowing the number and proportion of signalised intersections in an area of interest can be used in combination with vehicle density calculations to estimate costs.

4 Cost Evaluation Findings

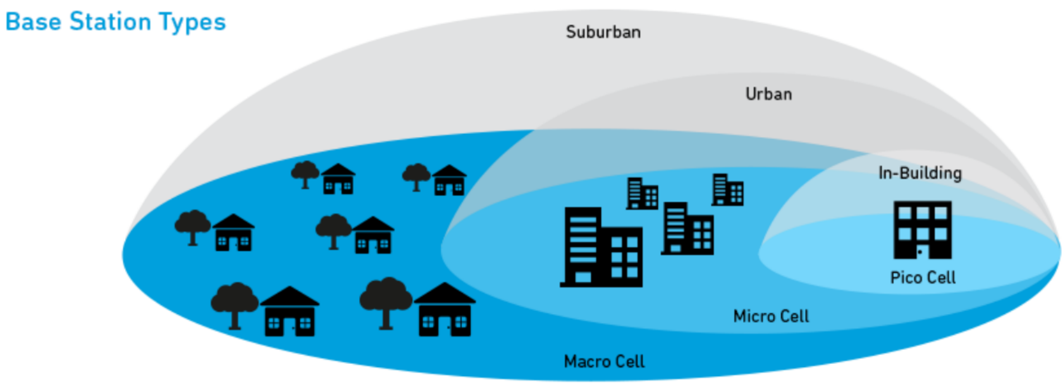
Perspective 1 "How much does the infrastructure cost to implement?"

In this section we will present the costs and discuss the considerations when applying the details at scale. As ICT4CART use cases adopted a hybrid communication approach (4G/LTE, 5G and ETSI ITS G5) both wireless communication networks will need to be costed for any application.

For 5G V2X deployment, the road user density and bandwidth needed will determine which band of the spectrum will be deployed in different locations. Very generally, the urban locations will demand medium (3.5-6GHz) to high (24-40GHz-) 5G frequency bands providing higher bandwidth but also shorter range resulting in the need for more base stations or small cells.

Rural locations will most likely be serviced by macro cells utilizing the >1Ghz frequency range with up to a 30 km radius. The trade-off is that the available bandwidth will be lower, only incrementally better than 4G/LTE available today. The lower bandwidth will be unlikely to be an issue as the density of roads, intersections, and vehicles will be lower.

Figure 12: 5G Base Station Types (Image used courtesy of Qorvo)



Cell Type	Output Power (W)	Cell Radius (km)	Users	Locations
Femtocell	0.001 to 0.25	0.010 to 0.1	1 to 30	Indoor
Pico Cell	0.25 to 1	0.1 to 0.2	30 to 100	Indoor/Outdoor
Micro Cell	1 to 10	0.2 to 2.0	100 to 2000	Indoor/Outdoor
Macro Cell	10 to >50	8 to 30	>2000	Outdoor

QORVO

4.1 Common Elements

In addition to the costs outlined below the US Department of Transportation provides a national database of cost estimates for ITS deployments: https://www.itskrs.its.dot.gov/costs. In addition to costs the databased also contains detailed benefits of a range of ITS deployments.

4.1.1 LTE/5G RAN

While MNO communications infrastructure is not being considered in detail for this report, there is a very detailed list of costs available (Widelity, Inc., 2021). Table 14, contains the cost for a 50 Site Microwave and transport core network.

1) Access Layer
   a) 500 Fixed Wireless CPE
2) Distribution Layer – 50 sites with:
   a) eNodeB supporting 3 B12/700 radios and 3 B25/PCS radios
   b) 200 foot towers with 6 Radios, 6 antennas and cabling and over voltage protection
   c) Cabinet with Power Distribution, Batteries, Rectifiers
   d) Cell Site Routers
   e) Microwave Hop
3) Core Layer
   a) 20K Subscribers
   b) Enhanced Packet Core (SGW, PGW, MME, PCRF)
   c) IMS Core
   d) Subscriber Management (HSS, AAA)
   e) Aggregation Router
4) Software
   a) RAN Element Management
   b) Packet Core Element Management
   c) IMS Element Management
   d) Routing (cell site router and aggregation router) Element Management
   e) PCMD Call Trace Network Tool
5) Services
   a) Site Acquisition
   b) Logistics and Warehousing
   c) Installation, Commissioning, Integration of 50 RAN sites
   d) Installation, Commissioning, Integration of Core site
   e) RF Design, Optimization, KPI Monitoring
   f) Program Management / Governance
   g) Equipment Removal (at a 2nd visit later in time)
   h) E2E Testing Across RAN/MW/Core/IMS
   i) Security Audit
   j) Resident Engineer (6 months)
   k) Training

Table 14: Example for a 50 Site MW and Transport core Network

FCC Layer	Catalogue of Costs - Low USD$	Catalogue of Costs – High USD$
Access Layer - CPE	$135,000.00	$267,500.00
Distribution Layer – 50 eNodeBs	$2,400,000.00	$5,350,000.00
Distribution Layer – Antennas, OVP, Cabling, Backup Power (at each eNB site)	$1,679,000.00	$4,540,350.00
Distribution Layer – 50 Cell Site Routers and 50 Microwave Hops	$599,520.00	$3,160,000.00
Core Layer – EPC, IMS and Aggregation Router	$1,412,500.00	$3,357,352.00

FCC Layer	Catalogue of Costs - Low USD$	Catalogue of Costs – High USD$
Software Layer – eNodeB, EPC, IMS and Routing Element Management +Tools	$600,000.00	$1,490,000.00
Services Layer – Per Site Deployment Services	$5,726,000.00	$14.873,150.00
Services Layer – EPC, IMS, Aggregation Router and E2E Testing	$1,852,000.00	$4,576,839.00
Total	**$14,404,020.00**	**$37,615,191.00**

Source: (Widelity, Inc., 2021)

It is estimated that the 10-year total cost of ownership of 5G small cell infrastructure covering for one kilometre of roadway (UK A&B roads) is £31,605.13 (€36,638) (Oughton & Frias, 2016). Motorways were slightly less at £31,532.47 (€36,554) per kilometre.

4.1.2 ITS-G5 RAN

ICT4CART collaborator ASFiNAG manages 2249 highway kilometres and recently completed the procurement, installation and operation of central and roadside C-ITS components based on WLAN (ITS-G5) for 12 years (17 years maximum). Only one-quarter of the entire road network will be covered at the cost of €14,451,360.20 or €25,703 for each kilometre.

Table 15: Overview of infrastructure costs by technology

Cost type	Cost element	Base value[52] (2016)					
		New RSU (EUR)			Replaced RSU (EUR)		
		Traditional	PC5	802.11p	Traditional	PC5	802.11p
Capex (one-off cost)	Equipment	1200	3500	3500	1200	3500	3500
	Hardware installation	1500	1000	1000	1500	1500	1500
	TOTAL CAPEX	**2700**	**4500**	**4500**	**2700**	**5000**	**5000**
Opex (annual cost)	Backhaul	200	200	200	200	200	200
	Security	40	40	40	40	40	40
	Power consumption	20	20	20	20	20	20
	Maintenance	150	225	225	150	225	225
	TOTAL OPEX	**210**	**285**	**285**	**210**	**285**	**285**

Source: (Rebbeck, et al., 2017)

Various component costs of the ITS-G5 RAN can be found throughout the following sections.

4.2 Smart Parking Use Case Cost Model (UC1)

UC1 Smart Parking Costs based on functional Diagram of Scenario 1.1 from D7.2. Smart Parking sensor costs have been included for interest but were not used in Scenario 1.1.

Figure 13: Functional Diagram of Scenario 1.1 from D7.2.

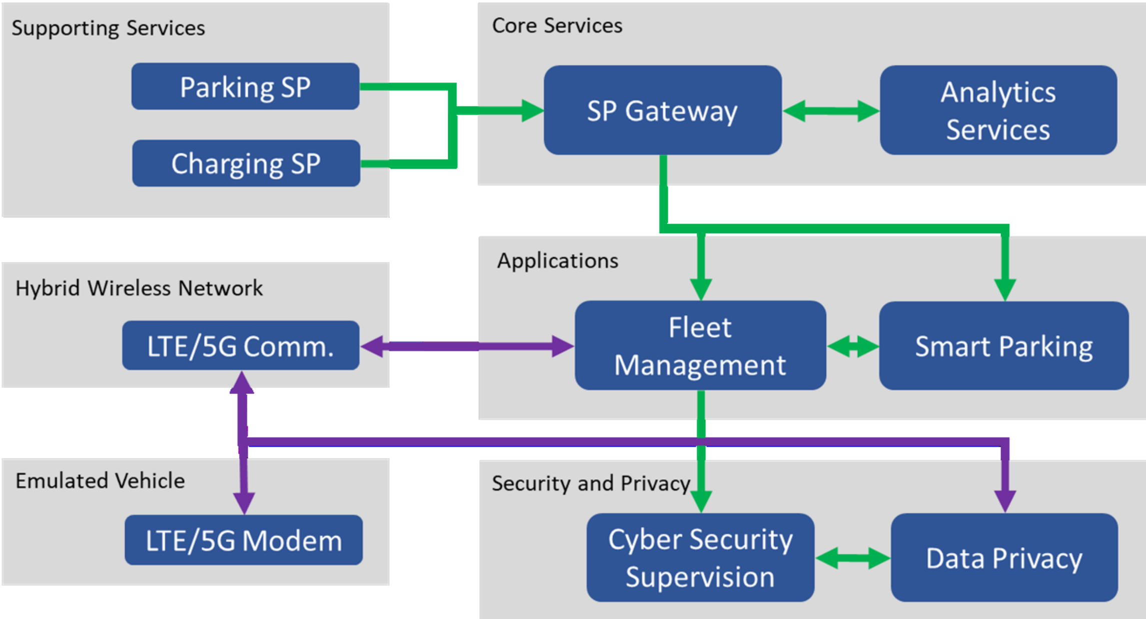


Table 16, contains the costs that were available during this research and highlights some of the missing components. Scaling the cost of the Smart Parking use case is based on the number of parking spaces available on the platform.

Table 16: Smart Parking Costs

Capital Expenditure	**#**	**Estimate €**	**Total Estimate €**	**Notes**	**Partner**
HMI (Tablet / Smartphone)	1	€ 600	€ 600		BMW
Modem LTE/5G	1	€ 750	€ 750		
Sensor Gateway	*1*	*€ 2,024*	*€ 2,024*	*Qfree ParQSense Base Station (30 Sensors)*	
Parking Sensor	*30*	*€ 202*	*€ 6,066*	*Nwave LoRaWAN Sensors (Bosch similar price)*	
Operating Expenditure	**#**	**Estimate**	**Total Estimate**		
Remote Install Support	*1*	*€ 2,240*	*€ 2,240*	*30 Sensors, remote install support (16 Hours)*	
LTE/5G Subscription		1	€ 120		
Missing / Unavailable	**#**	**Estimate**	**Total Estimate**		
Smart Parking Platform					City of Ulm
Fleet Management Platform					BMW

Service Provider Gateway					IBM IE
Analytics Services					
Cybersecurity & Privacy					
TOTAL			**€ 11,800**		

Figure 14: Smart Parking Adoption Prediction show the adoption rate under Market Scenario 5 from D2.2. The coefficients for other Marker Scenarios can be found in Table 17.

Figure 14: Smart Parking Adoption Prediction

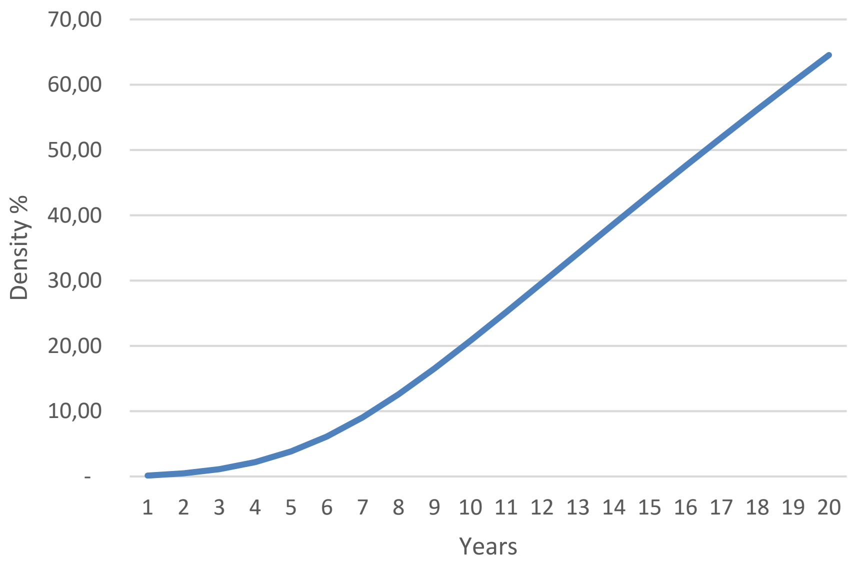


Table 17: Smart Parking Adoption Model by Market Structure

Market Structure	Infrastructure financed by...	CAV Service funded by...	Total Addressable Market	Coefficient of external influence (advertising) (p)	Coefficient of internal influence (network) (q)
1	Public	Public	Parking Users	Medium	High
2	Public	Private/User	Parking Users	Medium	Medium
3	Private/User	Public	Parking Users	Medium	High
4	Private/User	Private/User	Parking Users	Medium	Medium
5	Combination	Combination	Parking Users	Medium	High

4.3 Dynamic Adaptation Use Case Cost Model (UC2)

UC2 Dynamic Adaptation Costs based on the functional Diagram of Scenario 2.3 from D7.2

Figure 15: Functional Diagram of Scenario 2.3 from D7.2.

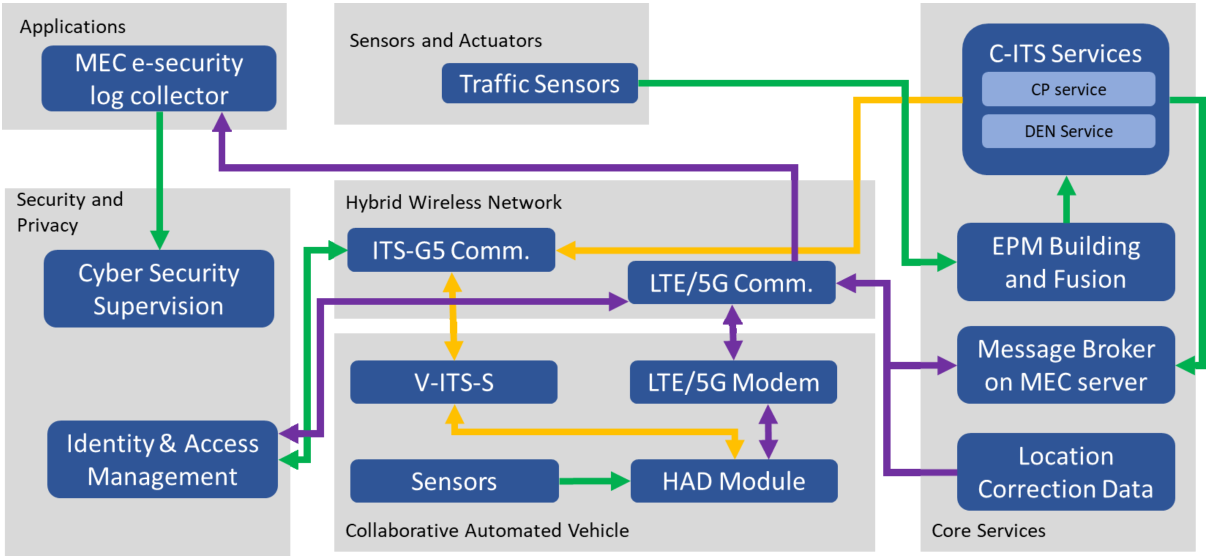


Table 18, contains the costs that were available during this research and highlights some of the missing components. Scaling the cost of the Dynamic Adaption use case will be driven by the linear kilometres or roadways and the density of vehicles that need to be serviced.

Table 18: Dynamic Adaptation

Capital Expenditure	#	Estimate €	Total Estimate €	Notes	Partner
ITS-G5 RSU	2	€ 2,000	€ 2,000		LINKS
LTE/5G Base Station	1	€ 13,000	€ 13,000	LTE Extension with additional frequency layer per site, carrier aggregation	Wind-Tre, T-Mobile
OBU ITS-G5	1	€ 700	€ 1400		
OBU Modem LTE/5G	1	€ 750	€ 1,500		
Multi Access Edge Computing	1	€ 69,644	€ 139,288		Wind-Tre, T-Mobile
RSU Installation, Configuration	2	€ 750	€ 750		SWARCO
LTE/5G Install & Integration	1	€ 22,990	€ 22,990		Wind-Tre, T-Mobile
MEC Onboarding, Config	2	€ 28,650	€ 57,300		Wind-Tre, T-Mobile
Operating Expenditure	**#**	**Estimate**	**Total Estimate**		
RSU Repair & Maintenance fixed p.a.	1	€ 30,000	€ 30,000	Support hundreds of units.	SWARCO

RSU Repair & Maintenance per unit p.a.	2	€ 150	€ 300		SWARCO
LTE/5G Carrier Aggregation	1	€ 1,650	€ 1,650		Wind-Tre, T-Mobile
MEC Data Centre Cost	1	€ 9,000	€ 9,000		Wind-Tre, T-Mobile
Missing / Unavailable	**#**	**Estimate**	**Total Estimate**		
AMQP Broker	2				SWARCO
CCTV				Part of the Collective Perception Service, monitoring the status of the intersection, including non-CAV users and vulnerable road users (cyclists and pedestrians).	Comune di Verona
Cybersecurity & Privacy					
Vehicle & ADS	1				CRF/Bosch
Environment Perception Model					LINKS
C-ITS Services	2				
TOTAL			**€ 122,740**		

Figure 16: Dynamic Adaptation Adoption Model Prediction, show the adoption rate under Market Scenario 5 from D2.2. The coefficients for other Market Scenarios can be found in Table 19.

Figure 16: Dynamic Adaptation Adoption Model Prediction

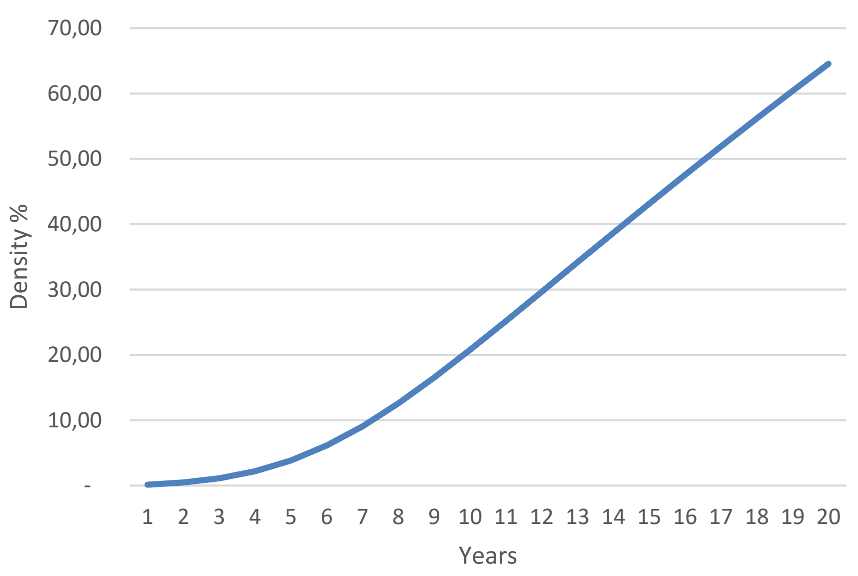


Table 19: Dynamic Adaptation Adoption Model by Market Structure

Market Structure	Infrastructure financed by…	CAV Service funded by…	Total Addressable Market	Coefficient of external influence (advertising) (p)	Coefficient of internal influence (network) (q)
1	Public	Public	Vehicle Operators	Low	High
2	Public	Private/User	Vehicle Operators	Low	Medium
3	Private/User	Public	Vehicle Operators	Medium	High
4	Private/User	Private/User	Vehicle Operators	Medium	Medium
5	Combination	Combination	Vehicle Operators	Medium	High

4.4 Virtual Mirror Use Case Cost Model (UC3)

UC4 Virtual Mirror Costs based on the functional diagram of Scenario 3.1a from D7.2

Figure 17: Functional Diagram of Scenario 3.1a from D7.2.

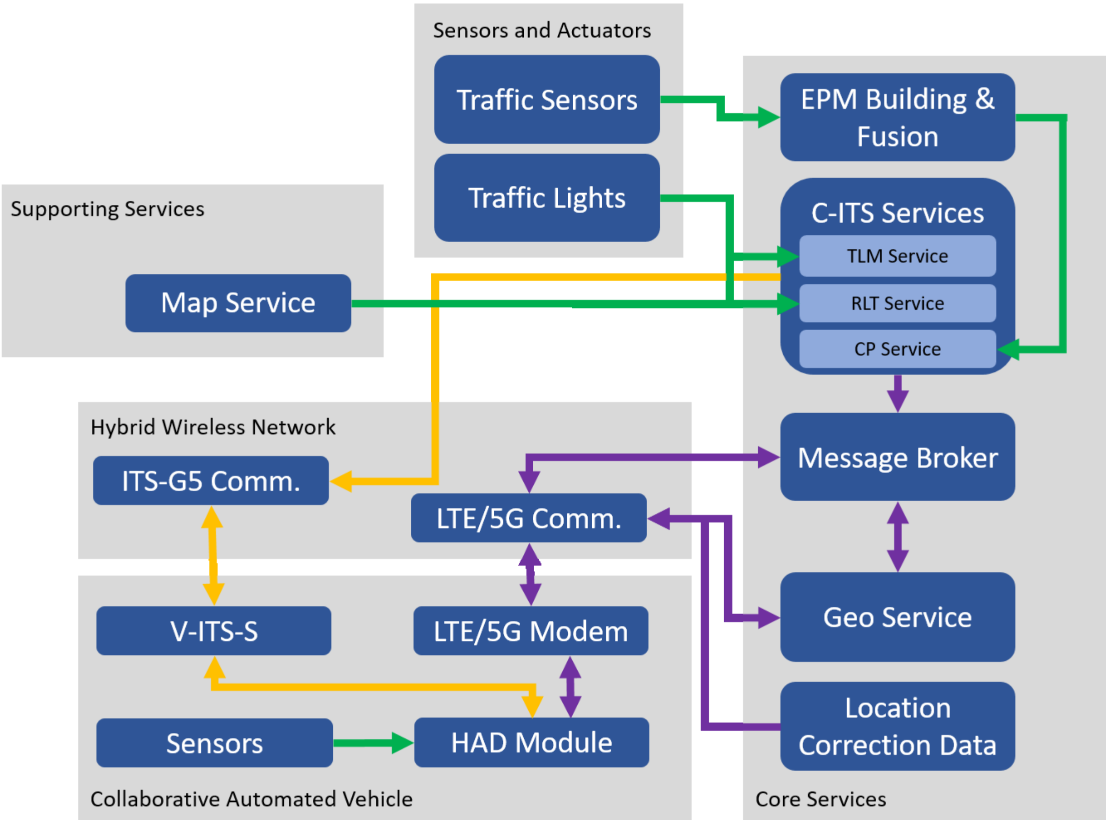


Table 20, contains the costs that were available during this research and highlights some of the missing components. For the Virtual Mirror use case scaling the costs will be defined by the intersection density and in turn, vehicle density that needs to be serviced by the solution.

Table 20: Virtual Mirror Costs

Capital Expenditure	#	Estimate €	Total Estimate €	Notes	Partner
ITS-G5 RSU	2	€ 2,000	€ 4,000		SWARCO
LTE/5G Base Station	1	€ 13,000	€ 13,000	LTE Extension with additional frequency layer per site, carrier aggregation	T-Mobile
OBU ITS-G5	1	€ 700	€ 700		
OBU Modem LTE/5G	1	€ 750	€ 750		
Multi Access Edge Computing	1	€ 69,644	€ 69,644		Nokia
RSU Installation, Configuration	2	€ 750	€ 1,500		SWARCO
LTE/5G Install & Integration	1	€ 22,990	€ 22,990		T-Mobile
MEC Onboarding, Config	1	€ 28,650	€ 28,650		Nokia
Operating Expenditure	**#**	**Estimate**	**Total Estimate**		
RSU Repair & Maintenance fixed p.a.	1	€ 30,000	€ 30,000	Support hundreds of units.	SWARCO
RSU Repair & Maintenance per unit p.a.	2	€ 150	€ 300		SWARCO
LTE/5G Carrier Aggregation	1	€ 1,650	€ 1,650		T-Mobile
MEC Data Centre Cost	1	€ 9,000	€ 9,000		Nokia
Missing / Unavailable	**#**	**Estimate**	**Total Estimate**		
AMQP Broker	1				SWARCO
Vehicle & ADS	1				Ulm University
Geo Service (Precise Positioning)	1				T-Mobile
Environment Perception Model	1				Ulm University
C-ITS Service	1				
TOTAL			**€ 94,090**		

Figure 18: Virtual Mirror Adaptation Adoption Model show the adoption rate under Market Scenario 5 from D2.2. The coefficients for other Marker Scenarios can be found in Table 21.

Figure 18: Virtual Mirror Adaptation Adoption Model

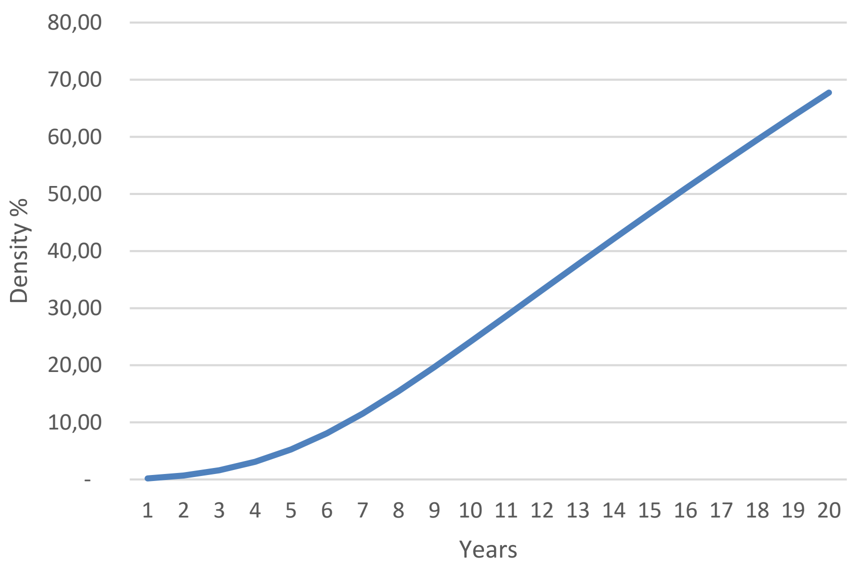


Table 21: Virtual Mirror Adoption Model by Market Structure

Market Structure	Infrastructure financed by…	CAV Service funded by…	Total Addressable Market	Coefficient of external influence (advertising) (p)	Coefficient of internal influence (network) (q)
1	Public	Public	Vehicle Operators	High	High
2	Public	Private/User	Vehicle Operators	High	Medium
3	Private/User	Public	Vehicle Operators	High	High
4	Private/User	Private/User	Vehicle Operators	High	Medium
5	Combination	Combination	Vehicle Operators	High	High

4.5 Cross Border Use Case Cost Model (UC4)

UC4 Cross Border Costs based on functional Diagram of Scenario 4.1 from D7.2

Figure 19: Functional Diagram of Scenario 4.1 from D7.2

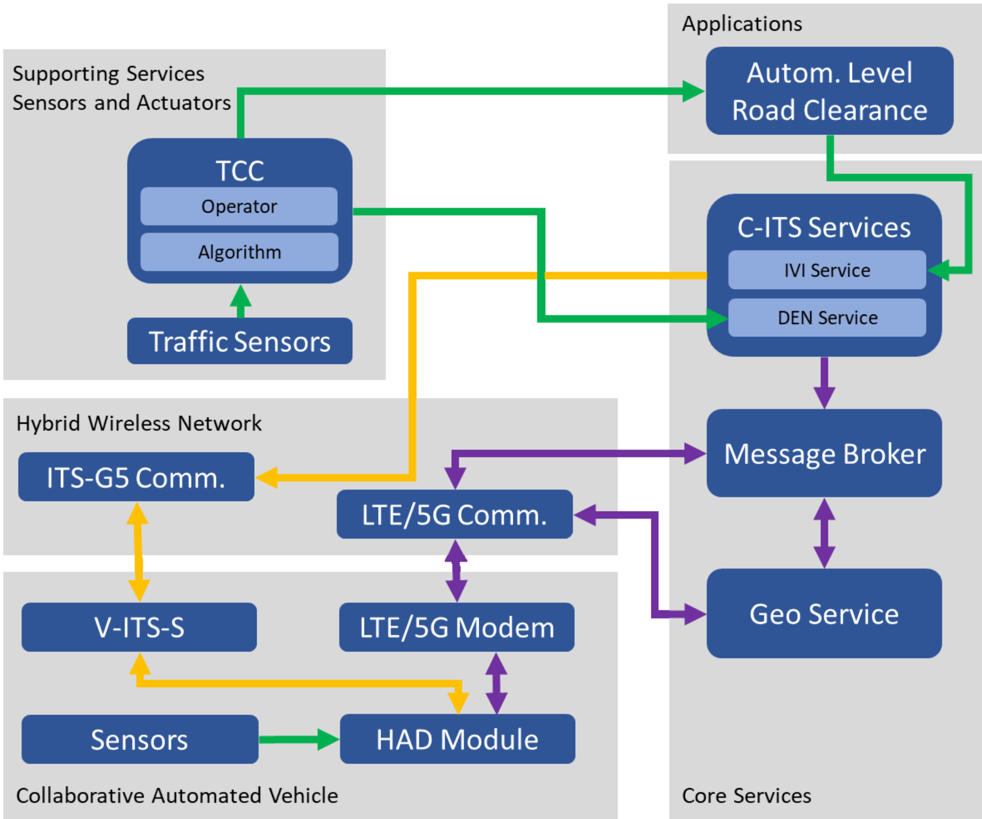


Table 22, contains the costs that were available during this research and highlights some of the missing components. In the Cross Border use cases, the infrastructure was replicated on each side of the border.

Table 22: Cross Border Costs

Capital Expenditure	#	Estimate €	Total Estimate €	Notes	Partner
ITS-G5 RSU	2	€ 2,000	€ 4,000		SWARCO
OBU ITS-G5	2	€ 700	€ 1400		
OBU Modem LTE/5G	2	€ 750	€ 1,500		
Multi Access Edge Computing	2	€ 69,644	€ 139,288		
Traffic Control Centre	2	€ 330,000	€ 660,000	Software platform only, likely to already be in place for many locations	SWARCO
RSU Installation, Configuration	1	€ 750	€ 750		SWARCO
MEC Onboarding, Config	2	€ 28,650	€ 57,300		

Operating Expenditure	#	Estimate	Total Estimate		
RSU Repair & Maintenance fixed p.a.	1	€ 30,000	€ 30,000	Support hundreds of units.	SWARCO
RSU Repair & Maintenance per unit p.a.	1	€ 150	€ 150		SWARCO
MEC Data Centre Cost	2	€ 9,000	€ 18,000		
Missing / Unavailable	**#**	**Estimate**	**Total Estimate**		
AMQP Broker	2				SWARCO
Vehicle & ADS					Bosch
Geo Service (Precise Positioning)	1				SwiftNav
C-ITS Service	2				C-ROADS
TOTAL			**€ 912,388**		

Figure 20: Adoption rate under Market Scenario 5 from D2.2. The coefficients for other Marker Scenarios can be found in Table 23.

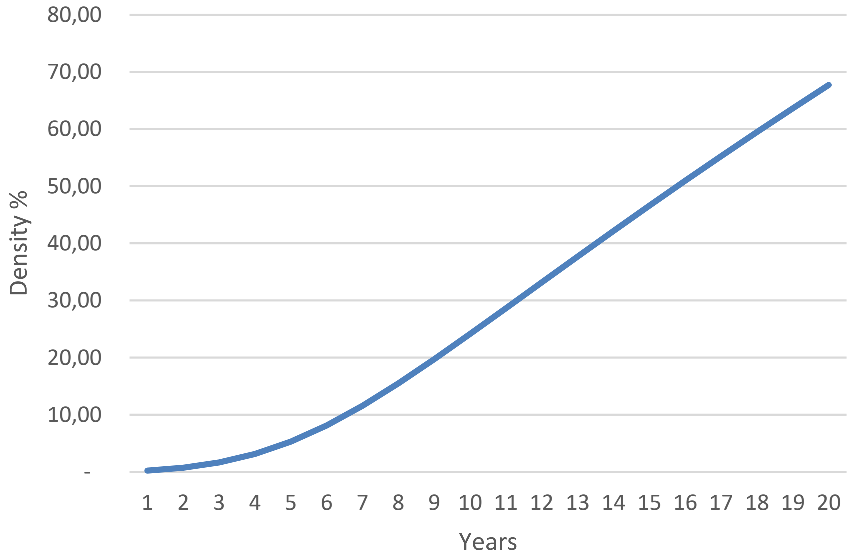


Table 23: Cross Border Adoption Model by Market Structure

Market Structure	Infrastructure financed by…	CAV Service funded by…	Total Addressable Market	Coefficient of external influence (advertising) (p)	Coefficient of internal influence (network) (q)
1	Public	Public	Vehicle Operators	High	High
2	Public	Private/User	Vehicle Operators	High	High
3	Private/User	Public	Vehicle Operators	High	High
4	Private/User	Private/User	Vehicle Operators	High	High
5	Combination	Combination	Vehicle Operators	High	High

5 Market Sustainability Findings

Perspective 2 “Who is willing to pay how much for the service?”

5.1 Smart Parking (UC1)

Smart Parking refers to a number of parking related systems that can have different beneficiaries or customers. The most recognised function of Smart Parking is the identification of open parking spaces either on street or in parking garages using a smartphone or in-vehicle application. This identification function often will be complemented with the ability to use mobile and digital payment to reserve and pay for the space. While the user will be fleet or vehicle operators, the paying customer for the Smart Parking solution is less clear.

Another Smart Parking function is to support parking enforcement by alerting officials to parking violations. Some Smart Parking solutions incorporate hardware such as embedded road sensors to identify the presence of vehicles to assist officials in identifying parking violations. Connected hardware sensors can provide an additional source of revenue in addition to the core digital Smart Parking solution. The paying customer will be RNO’s and other parking facility operators.

Additionally, the data and analytics generated by Smart Parking solutions can be used by financial services firms, real estate developers, planners, municipalities to understand parking activity, utilisation, pricing and the impact of restrictions. The paying customer will be RNO’s and other parking facility operators.

According to the British Parking Association, drivers spend an average of 5.9 minutes looking for a [parking] space, with 44% of those polled calling the endeavour a “stressful experience” (England, 2017).

Research shows that where smart parking systems have been installed,

- the time taken find a parking space can be reduced by up to 43%,
- vehicle miles travelled can be reduced by 30%
- and traffic volume decreased by 8%.

The monetary benefit of the increased revenue attributable to the use of smart parking technologies was $98.70 per parking space (GSM Association, 2017). There is a clear direct benefit to users but an even more impactful benefit for RNO’s as more efficient parking results in less congestion.

ICT4CART partner BMW reported in D8.3 Technical Evaluation that in their Ride-hailing Simulator the use of Smart Parking resulting in fleet cost reductions. These reductions ranged from 5% to 70% and the increased profit from 50% to 190%, with some exceptions which are either too high or even some reductions in profit.

For this report, we are focussed on the application of Smart Parking solutions in CAV’s but will use the existing widespread adoption of smartphone-based Smart Parking solutions to guide the market and pricing details. Smart Parking solutions are well on their way to being integrated into vehicles as a number of solution providers have products for OEM integration and smartphone applications are easily ported into systems such as Android Auto (RingGo, 2022). Various collaborations have enabled in-vehicle payments for smart parking (Li, 2021) and EV charging (Parkopedia, 2022). OEMs such as ICT4CART partner BMW are already deploying Smart Parking applications in modern vehicles (BMW, 2021).

5.1.1 Customer

The customer is the user of the ICT4CART infrastructure providing the Smart Parking Use Case. In this case of Smart Parking, it will be the vehicle operators, parking facility operators, RNO's and other solution providers or a combination thereof depending on the business models.

Parking facility operators commonly offer smartphone applications with varying levels of sophistication to improve the customer experience and streamline their operations. With the existing penetration of free Smart Parking smartphone applications, it will be difficult to justify charging a fee directly to vehicle operators just for the use of the application. If end users can't differentiate between this information service and how they currently access parking data (for free), then they will not be willing to pay extra for it.

As an example, Indigo is a parking operator who simply has a smartphone application that makes parking easier for customers. It is a tool providing a better customer experience they can spend more money on the core revenue generator, the parking space.

Vehicle operators do indirectly finance the Smart Parking solution, if it isn't an additional service fee it will be included in the cost of the parking space. This dynamic effectively makes the owner or operator of the parking facility or space the true customer of any Smart Parking solution.

Table 24: Smart Parking Companies.

Company	Website	Target Market	Application Costs
Parkopedia	parkopedia.com	OEM, Facilities, Fleets, Solution Providers (Navigation), Analytics	US$5.49 Premium Features
Flowbird (Parkeon)	flowbird.group	Facilities, Fleets, Corporate, Solution Providers and Public	Free Smartphone Application (£0.20 Fee for SMS services)
PaybyPhone	paybyphone.com	Facilities, Fleets and Public	Free Smartphone Application (£0.04 to £0.20 SMS fee)
Indigo OPnGo	opngo.com	Facilities, Public	Free Smartphone Application
AppyWay, AppyParking	appyway.com	Facilities, Fleets and OEM's	Free Smartphone Application
ParkNow, Easy Park	parknowgroup.com		
RingGo	ringgo.co.uk	Facilities, Fleets and Public	Free Smartphone Application (£0.10 SMS fee, £0.20 service fee)
JustPark.	www.justpark.com	Facilities, Fleets, Corporate and Public	£0.49 service fee for private spaces, £2.40 mth fee per corporate user
APCOA Connect		APCOA Facility Users	

One of the only circumstances under which the end-user may pay for the use of a smart parking data may be if it was bundled with a suite of tools that came with their vehicle. Even then, the cost would be negligible and longer-term unsustainable for the provider. End-users may pay for this service through elevated parking charges, or a subscription charge that bundles together a series of in-car services.

What vehicle operators have proven to be willing to pay for is booking and paying for the parking space via transaction or service fee.

5.1.2 Market

The global Smart Parking market is estimated to reach US$19.29 bn in 2028 (Grand View Research, 2022).

Location can have a significant impact on parking utilisation. Common location-based parking can include travel such as airports, bus and train stations, City and shopping centres, healthcare and education facilities and events and hospitality (cinema, casino, stadiums etc.). In addition, there is also on street and private parking. Some Smart Parking providers are enabling people to offer their driveway and EV charging facilities for rent to the public (JustPark, 2022).

In 2013 it was estimated that there were 47,124,388 regulated spaces in Europe consisting of 30,167,672 off-street and 16,956,716 on street spaces (European Parking Association, 2013).

These estimates do not include private parking spaces such as driveways or unregulated kerbside parking space which were estimated to be over 190mm spaces.

As with many data provision service standardisation limits the market opportunity. As some data sets such as parking (Weilandt, 2017) and charging infrastructure (Alliance for Parking Data Standards, 2022) become standardised and centralised the services will become more authoritative and enabling. Currently, Parkopedia[3] is the largest provider of parking information and is a good example of a company having success with Smart Parking data.

Until there is a common parking data source or language (similar to EV charging infrastructure) then it will be difficult for OEM's to commit to a single parking platform. Over the air (OTA) updates would allow for the deployment of regional parking apps but this is many years away. Parking data will likely become part of regional smart city platforms commissioned (concession) by the local authority and made available to any Smart Parking provider.

5.1.3 Pricing

Models for Smart Parking can range from a revenue share where the solution provider charges either a fixed fee or percentage per transaction through to a regularly occurring license fee for the solution. There are also often various setup fees involved.
Some solution providers do charge an additional fee for using their service as a part of the payment transaction. The challenge with this type of fee is that it can just as easily be for the payment transaction itself rather than the provision of the parking booking service. Additionally, solution providers can charge for additional services such as SMS transaction confirmation and SMS reminders that your parking is expiring (£0.20 each).
We have found service fees ranging from free, £0.05 (Harris, 2020), £0.15 (Durham City Council, 2022), USD$0.20 (Hwang, 2021) to £0.35.

The average cost of parking in the 32 European cities is €3 an hour (Euronews, 2016). In the UK the average cost of parking for 2 hours was GBP£3.00 (Inrix, 2017)

[3] https://www.parkopedia.com/

Some metropolitan areas choose to absorb the service fee rather than pass it on to customers. In the case of Seattle, WA this represents USD$490,000 annually for the 1.4mm transactions that were being charged USD$0.35 (PayByPhone, 2017). This suggests that the per-transaction service is being paid in all scenarios but can either be absorbed by the facility operator or passed directly onto the vehicle operator. This pay per use model makes sense as the revenue is based on the utilisation of the Smart Parking service.

There is a huge range of factors that influence the utilisation of parking space including distance to destination (location) and nearby land use to driver behaviour and psychology.

As revenue for Smart Parking solution providers to be made up of per-transaction fees we would need the total number of transactions to accurately understand the market potential. While we have been able to locate metrics for turnover, the number of spaces, occupancy rate etcetera finding the number of visits or transactions remains elusive. This is likely due to the fact that every parking location has very different utilisation metrics. The difficulties involved in obtaining accurate parking data is supported by the existence of a dedicated parking survey industry4.

Using the (2013) data we have available we conservatively estimate that the European Smart Parking application market is worth **€711,054,655** annually.

The average revenue per space in Europe is €679.00 (European Parking Association, 2013). Dividing €679.00 by the average hourly parking rate of €3.00 (Euronews, 2016) we have 226.33 hours annual utilisation per parking space. Dividing the 226.33 hours by a conservative estimate of 3 hours average parking stay, results in 75.4 parking transactions per space annually. 75.4 parking transactions multiplied by the 47,124,388 (European Parking Association, 2013) regulated parking spaces in Europe suggests 3,555,273,272 parking transactions with a service fee of €0.20 results in a €711,054,655 annual European market opportunity for Smart Parking technology providers.

This calculation is just for per transaction service fees and doesn't include installation setup fees or other fees for services such as SMS notifications. Service fees could be paid by the end-user or the facility operator. As detailed in the proposals we have sighted, we assume that credit card transaction fees are paid within the cost of the parking space and do not impact the service fee. The potential number of parking spaces in Europe that are not yet regulated is far greater (>190mm spaces).

5.2 Dynamic Adaption (UC2)

The aim of Scenarios 2.1, 2.2 and 2.3 is the dynamic adaptation of vehicle automation level based on infrastructure information. To enable the comfortable and safe automated driving for SAE Level 3/4 automated vehicles, the vehicle will receive information from sensors from the road infrastructure (e.g. on traffic density) and make the decision to hand over control to the human driver or come to a safe stop. The information that is received can demand either an immediate or longer term response. The response can be for the ADS to avoid an identified situation or relinquish control to a human driver.

Prescriptive notifications like those based on the application of the Infrastructure Classification Scheme for Automated Driving (ISAD) will most likely be integrated into HD Map and navigation data sets in much the same way that speed limits are today.

[4] https://nationwidedatacollection.co.uk/parking-surveys/, https://www.aparking.co.uk/, https://parkinglogix.com/

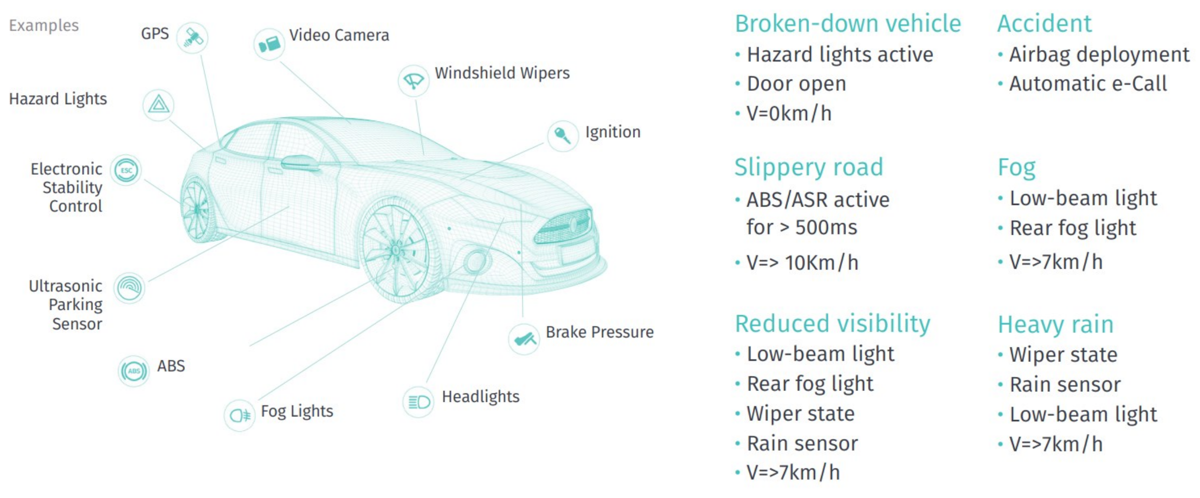
With the current activity in ADS development there is still a heavy reliance on backup drivers so the need for relinquish control to a human driver does exist, albeit in a very limited market. This is effectively a failover situation moving the level of autonomy from level 4 to 3. Although, looking ahead there is a trend for CAV innovators and OEMs to skip level 3 for level 4 autonomy (Henry, 2021). The reliance on fallible humans to take control at short notice raises liability issues and isn't in alignment with customer expectations. It is now expected that completely driverless robotaxis will be deployed in volume in 2023 by Motional (Motional, 2021) in Las Vegas, 2024 by Aurora (Ohnsman, 2021) in San Francisco and AutoX are expanding in China (AutoX Team, 2022) amongst many others.

The trend towards level 4 autonomy is reinforced by the fact that in the United States OEMs no longer need to include manual controls in vehicles that have automated driving systems (Hutton, 2022). This new rule effectively removes the decades old assumption that there will be human occupant ready to take control of the vehicle.

The Dynamic Adaption use case will likely have longer term application handing over the vehicle control to a remote teleoperation facility if the CAV encounters road hazards, circumstances it doesn't recognise (edge cases) or other failure. The other remaining alternative to simple to instruct the vehicle to come to a complete stop.

The underlying messaging services that signals a human driver or ADS to take actions is readily available in the market.

Figure 21: Example data required to generate a HERE Hazard Warning for other CAV's



Source: (HERE Technologies, 2021)

TomTom is another provider that provides Hazard Warning data service based on the MQTT platform. MQTT is a client-server publish/subscribe messaging transport protocol that is lightweight, open, simple and designed to be easy to implement (TomTom, 2020).

5.2.1 Customer

The initial customer is the OEM who may pass the costs on to vehicle operators through a subscription service.

5.2.2 Market

Notifications (CAM/DEMN) arising from the immediate infrastructure will largely going to be safety related and unlikely to be something vehicle operators will pay for. Notifications that are more convenience related that impact comfort over the longer journey have already proven to be services that vehicle operators or passenger will pay for. Although anecdotally the uptake of these services are very low.

As the services underlying Dynamic Adaption become more sophisticated and readily available in new vehicles the adoption and willingness to pay for the service should increase. The onset of automation is likely to provide an accelerated rate of adoption.

5.2.3 Pricing

All of the services listed in Table 25 claim to provide varying level of live information that do include event such as traffic jams, incidents, newly blocked lanes, active road construction, and other traffic delays that couple potentially impact the operation of an automated vehicle.

Table 25: Dynamic Adaption comparable supporting data services.

Company	Platform	Service	Annual Subscription
BMW	ConnectedDrive	Safety Camera Information[5]	>€23.26 (£20.00)
Road Angel	NA	Basic – Complete Plus[6]	€115.14 - €348.89 (£99.99 - £299.99)
TomTom	Smartphone	GO Navigation[7]	€12.99
TomTom	SatNav	GO Discover[8]	€39.99
SirrusXM	SirrusXM	Traffic[9]	€40.49 ($3.99 Monthly)
HERE		Hazard Warnings	Dynamic[10]

Applying the adoption curve for Market Structure 4 from Table 28 suggests that in 10 years (2032) there will be 59,110,758 vehicles in Europe consuming the Dynamic Adaption data services. Assuming a €20.00 annual price results in a **€1,182,215,160** annual total addressable market.

To gain a more realistic market estimate the adoption model could be applied twice. The first application to obtain the adoption rate of the Dynamic Adaption into new vehicle by OEM as above, and then a second time to the 59,110,758 vehicles to estimate the number of vehicle operators using (subscribing) to the technology.

Additionally, there is a revenue stream from initial license fees for implementing the solution in new vehicles from the OEM's. This would most likely be a once off license per vehicle manufactured,

[5] https://www.bmw.co.uk/en/shop/ls/dp/Base_Safetycam_gb
[6] https://www.roadangelgroup.com/subscription
[7] https://www.tomtom.com/en_ie/navigation/mobile-apps/go-navigation-app/
[8] https://www.tomtom.com/en_ie/navigation/maps-services/go-discover-premium-services/
[9] https://www.siriusxm.com/infotainment?intcmp=Global%20Nav_NA_www:infotainment_TrafficWeatherMore
[10] https://www.here.com/pricing

separate from any subscription. An estimate of the license fee is not available.

5.3 Virtual Mirror (UC3)

The Virtual Mirror use case exploits the ICT4CART hybrid connectivity and MEC to create a 360° awareness around the vehicle with very low latency, creating a kind of "virtual mirror" or "collective perception" to support the automated vehicle undertaking manoeuvres such as crossing an intersection or merging into a lane.

The Virtual Mirror Use case is effectively the provision of the infrastructure enabling the deployment of a real time environmental perception model for CAV's.

5.3.1 Customer

It is unlikely that retrofit collective perception solutions will be available beyond R&D applications therefore the initial customer for the Virtual Mirror use case will be OEM's and their Tier 1 suppliers.

Similar to many other safety data oriented services being made available in transportation environments the RNO and/or vehicle operator will be the paying customer. The potential market dynamics exploring who will pay (public/private) was detailed in D2.2. The two most likely Market Scenarios are that the service is provided via an OEM. In which case the vehicle operator would pay a subscription fee. If the service is provided via the RNO it would either be publicly funded or the cost is passed directly onto the vehicle operator. We believe the chance of an RNO passing the costs directly on vehicle operators is least likely as it creates complication for users moving from one RNO's jurisdiction to another.

5.3.2 Market

Virtual Mirror solutions for CAV's are already close to market from influential industry partners (Leggett, 2021). The award-winning solution (Continental AG, 2021) from Continental and Iteris will combine their respective expertise in automotive and infrastructure data to provide "collective perception" and "transparent vehicle" solutions.

The collaboration between an automotive provider such as Their 1 suppliers and infrastructure data provider is a likely business model for the delivery of Virtual Mirror solution to market. IT both provides a channel to embed the supporting technology into new vehicles and the long-term source of real time infrastructure data enabling the use case long term.

5.3.3 Pricing

Many market research reports available that anticipate a significant general market for V2X solutions. The total addressable market range from USD$11,718.7 mm by 2027 (Bachal & Mutreja, 2021) to USD$18,877.1 mm by 2027 (Astute Analytica, 2022). Estimating the proportion of this market opportunity that applies to the Virtual Mirror use case is challenging.

An indicator that may be used as a proxy, is the value of deals that companies likely to provide Virtual Mirror capabilities are concluding. As a recent example a 3 year, US$6.8mm contract was awarded to Iteris to operationalise a V2I system across 88 intersections in Los Angeles (Spencer, 2022).

5.4 Cross Border (UC4)

The vision of automated and connected driving across Europe can only be realised through harmonised solutions that support cross-border traffic.

Cross-border interoperability enhances the possibility of providing cooperative, connected and automated driving services along different countries when vehicles drive across various national borders. Yet, the seamless provision of connectivity and the uninterrupted delivery of services might cause technical challenges. Thus, it is essential that harmonisation efforts are made to progress with the ICT interoperability across countries (handover, etc.).

While the synchronisation of back-ends of driving cases with other back-ends has been trialled, the handover between different back-ends for the development of a pan-European solution needs to be further trialled. For a vehicle to continue to receive C-ITS services across border requires the interoperability and handover of the application from one AMQP Message Broker to another.

This is an objective of ICT4CART and was successfully demonstrated per D8.3 Technical Evaluation. Cross Border interoperability between Italy-Austria at Brenner border supported the dynamic adaptation of vehicle automation level based on both accident and wrong-way driving warnings.

By its nature the Cross Border use case defines an underlying functionality that supports other CAV Services and enables their operation across borders.

5.4.1 Customer

From a user perspective, solutions comparable to the Cross Border use case are seamless. Cross Border services should function exactly the same was any mobile data service as users move between regions, base stations or access points irrespective of artificial borders or whether the connectivity is via LTE/5G or ITS-G5.

As such the users will view this service as core functionality of the network supporting the user experience and in the long term isn't a service that end users will pay for.

The customer for the ICT4CART cross border solution would be whomever wishes to host AMQP Message Brokers distributing C-ITS messages. Potentially every RNO or other agency responsible for regional road management across Europe is a customer for the Cross Border solution.

5.4.2 Market

At a minimum the market for the ICT4CART Cross Border solution would include every country in Europe. The most likely market scale would be defined by the number of motorway border crossings in Europe and the number of AMQP Message Brokers required to service those crossings.

5.4.3 Pricing

As the overall goal is to achieve the harmonization and deployment of interoperable cross-border C-ITS services across Europe it is unlikely that the core solution will be proprietary but will be freely available to all European nations.

Where revenue may be obtained based on the Cross Border use case is from the provision of services and expertise to implement the solution in different regions. This may be a dedicated initiative or more likely be part of a broader TCC installation or upgrade.

The confluence of broad variables needed to provide potential revenue estimate that could be obtained from a Cross Border product offering renders any estimated of little value.

- Hourly / daily rate of services.
- The scale of the project.
- Existing complementary infrastructure.
- The makeup of the entire solution being deployed.
- Portion of the solution being deployed.

6 Conclusions

This report has detailed the research undertaken to conclude on the market likelihood and sustainability of the ICT4CART solution and use cases. Since the ICT4CART project started, the industry and market have progressed, providing more clarity than may have been available earlier. While the supporting technology has progressed, the market is still in its earliest stages, providing an opportunity to define future market structures and business models. This has somewhat offset the challenges around obtaining cost data.

This report has provided the costs for the ICT4CART use cases in addition to other available cost details. Included are details and tools for assessing key variables such as vehicle and intersection density that directly influence the scalability of CAV infrastructure. These cost and tools serve as a basis for opportunity specific cost modelling by the reader to come to their own conclusion regarding sustainability. We have defined a model to estimate adoption rates of different technologies that has proven to be historically accurate but the acceleration (or limiting) influence of government policy is always an overriding factor for consideration. An evaluation of user demand, adoption modelling and exploration of comparable service pricing has provided an indication of market sustainability.

For **Smart Parking,** the existing market validates the sustainability of new and innovative services targeting the parking opportunity. While the competitive landscape is becoming crowded, the market is growing and there is a lot of opportunity for innovation.

Based largely on our findings into the already burgeoning market innovative Smart Parking solutions shows considerable promise and have a lot of potential as we move to autonomy and beyond.

We would suggest that readers specifically interested in the Smart Parking market also pay attention to the development of the curb side management and digitisation opportunity. Interest in making the curb side dynamic is growing and can be both an opportunity and a threat to traditional parking (Frost & Sullivan, 2022). Any growth in this market increases the demand for ICT4CART like solutions.

While an obvious innovation, there is a limited window of opportunity for the way **Dynamic Adaptation** has been envisaged during the ICT4CART project. Although, the underlying CAV Services that trigger the dynamic adaptation will be needed as long as there are connected vehicles on our roads. Real-time road and traffic condition alerts are available from many suppliers, and OEM are working towards sharing data to enhance granularity and availability.

Virtual Mirror is undeniably needed as we transition to autonomy. The presence of vehicles on our roadways that are not connected will demand that infrastructure play a supporting role in enhancing collective perception. The real value and sustainability of Virtual Mirror remains to be clarified as the market progresses, but the investments being made in developing the technology show promise.

Cross Border being a foundational solution supporting safety and other CAV Services, faces some challenges on the road to revenue. The implementation of Cross Border solutions may develop into an area of specialist expertise as a service, possibly provided by an MNO, as opposed to a technology product for sale. Cross Border will be an important and necessary component of CAV supporting infrastructure it is unlikely to be sustainable as an independent revenue-generating enterprise.

Overall, even in the absence of complete financial detail, we did not find any compelling road why the ICT4CART use cases would not be sustainable in the market if part of a suite of solutions. This confidence is largely supported by the fact that a lot of the infrastructure supporting the ICT4CART use cases will receive investment and widespread deployment irrespective of the application to connected vehicles. Additionally, many of the standards supporting the ICT4cart use cases are in advanced stages of development.

The short-term deployment of 5G, which will heavily influence the market for CAV solutions, will be driven by consumer mobile devices such as smartphones from which C-V2X will benefit. The viability of the hybrid solution tested during the ICT4CART project is still outstanding and will be decided by factors such as standardisation and government policy. It is becoming clear in the United States that C-V2X is the solution of choice moving forward.

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8 Annexes

8.1 Annex 1 – Currency Exchange

The annual average exchange rates for 2021 below will be uses throughout this report to convert the source prices into euros[11].

Table 26: Euro Currency Conversion 2021 Average

Source Currency	Exchange Rate
GBP £	1.162995
AUD $	0.634935
USD $	0.845662

[11] https://www.ofx.com/en-gb/forex-news/historical-exchange-rates/yearly-average-rates/

8.2 Annex 2 - Technology Adoption Rates

Table 27: Smart Parking (UC1) Adoption Projection

					% of new vehicles which are connected (%)					Cumulative number of vehicles which are connected (Qty)					Connected Vehicle Density (Percentage)				
Year	Our Analysis Year	Total Vehicles in Use	Of which are new	Cummulative new	Market Scenario 1	Market Scenario 2	Market Scenario 3	Market Scenario 4	Market Scenario 5	Market Scenario 1	Market Scenario 2	Market Scenario 3	Market Scenario 4	Market Scenario 5	Market Scenario 1	Market Scenario 2	Market Scenario 3	Market Scenario 4	Market Scenario 5
2018	-	273,033,330																	
2019	-	277,759,682	14,373,486	14,373,486															
2020	-	282,567,850	14,622,299	28,995,785															
2021	-	287,459,249	14,875,418	43,871,203															
2022	-	292,435,322	15,132,920	59,004,123	-	-	-	-	-	-	-	-	-	-					
2023	1	297,497,532	15,394,879	74,399,002	3	2	3	2	3	393,513	373,364	393,513	373,364	393,513	0.13	0.13	0.13	0.13	0.13
2024	2	302,647,373	15,661,372	90,060,374	7	6	7	6	7	1,422,937	1,297,176	1,422,937	1,297,176	1,422,937	0.47	0.43	0.47	0.43	0.47

2025	3	307,886,360	15,932,479	105,992,853	13	11	13	11	13	3,435,360	3,007,505	3,435,360	3,007,505	3,435,360	1.12	0.98	1.12	0.98	1.12
2026	4	313,216,036	16,208,279	122,201,131	21	17	21	17	21	6,875,209	5,797,042	6,875,209	5,797,042	6,875,209	2.20	1.85	2.20	1.85	2.20
2027	5	318,637,972	16,488,853	138,689,984	32	25	32	25	32	12,218,234	9,992,214	12,218,234	9,992,214	12,218,234	3.83	3.14	3.83	3.14	3.83
2028	6	324,153,765	16,774,283	155,464,267	45	35	45	35	45	19,839,013	15,903,864	19,839,013	15,903,864	19,839,013	6.12	4.91	6.12	4.91	6.12
2029	7	329,765,038	17,064,655	172,528,922	59	46	59	46	59	29,871,363	23,759,988	29,871,363	23,759,988	29,871,363	9.06	7.21	9.06	7.21	9.06
2030	8	335,473,446	17,360,053	189,888,976	71	57	71	57	71	42,164,012	33,647,872	42,164,012	33,647,872	42,164,012	12.57	10.03	12.57	10.03	12.57
2031	9	341,280,670	17,660,565	207,549,541	80	67	80	67	80	56,366,157	45,496,860	56,366,157	45,496,860	56,366,157	16.52	13.33	16.52	13.33	16.52
2032	10	347,188,420	17,966,279	225,515,819	87	76	87	76	87	72,067,840	59,110,758	72,067,840	59,110,758	72,067,840	20.76	17.03	20.76	17.03	20.76
2033	11	353,198,436	18,277,285	243,793,104	92	83	92	83	92	88,904,681	74,228,851	88,904,681	74,228,851	88,904,681	25.17	21.02	25.17	21.02	25.17
2034	12	359,312,488	18,593,674	262,386,778	95	88	95	88	95	106,599,540	90,584,506	106,599,540	90,584,506	106,599,540	29.67	25.21	29.67	25.21	29.67

2035	13	365,532,378	18,915,541	281,302,319	97	92	97	92	97	124,961,024	107,942,892	124,961,024	107,942,892	124,961,024	34.19	29.53	34.19	29.53	34.19
2036	14	371,859,938	19,242,979	300,545,297	98	94	98	94	98	143,865,031	126,116,276	143,865,031	126,116,276	143,865,031	38.69	33.91	38.69	33.91	38.69
2037	15	378,297,031	19,576,085	320,121,382	99	96	99	96	99	163,234,685	144,964,202	163,234,685	144,964,202	163,234,685	43.15	38.32	43.15	38.32	43.15
2038	16	384,845,554	19,914,957	340,036,339	99	98	99	98	99	183,024,274	164,386,458	183,024,274	164,386,458	183,024,274	47.56	42.71	47.56	42.71	47.56
2039	17	391,507,435	20,259,696	360,296,035	100	98	100	98	100	203,207,959	184,314,138	203,207,959	184,314,138	203,207,959	51.90	47.08	51.90	47.08	51.90
2040	18	398,284,636	20,610,402	380,906,437	100	99	100	99	100	223,772,322	204,701,420	223,772,322	204,701,420	223,772,322	56.18	51.40	56.18	51.40	56.18
2041	19	405,179,155	20,967,179	401,873,616	100	99	100	99	100	244,711,631	225,518,931	244,711,631	225,518,931	244,711,631	60.40	55.66	60.40	55.66	60.40
2042	20	412,193,022	21,330,132	423,203,747	100	100	100	100	100	266,024,898	246,748,789	266,024,898	246,748,789	266,024,898	64.54	59.86	64.54	59.86	64.54

ICT4 CART

Table 28: Dynamic Adaptation (UC2) Adoption Projection

					% of new vehicles which are connected (%)					Cumulative number of vehicles which are connected (Qty)					Connected Vehicle Density (Percentage)				
Year	Our Analysis Year	Total Vehicles in Use	Of which are new	Cummulative new	Market Scenario 1	Market Scenario 2	Market Scenario 3	Market Scenario 4	Market Scenario 5	Market Scenario 1	Market Scenario 2	Market Scenario 3	Market Scenario 4	Market Scenario 5	Market Scenario 1	Market Scenario 2	Market Scenario 3	Market Scenario 4	Market Scenario 5
2018	-	273,033,330																	
2019	-	277,759,682	14,373,486	14,373,486															
2020	-	282,567,850	14,622,299	28,995,785															
2021	-	287,459,249	14,875,418	43,871,203															
2022	-	292,435,322	15,132,920	59,004,123	-	-	-	-	-	-	-	-	-	-					
2023	1	297,497,532	15,394,879	74,399,002	1	2	3	2	3	178,389	354,509	393,513	373,364	393,513	0.06	0.12	0.13	0.13	0.13
2024	2	302,647,373	15,661,372	90,060,374	3	5	7	6	7	600,625	1,185,458	1,422,937	1,297,176	1,422,937	0.20	0.39	0.47	0.43	0.47
2025	3	307,886,360	15,932,479	105,992,853	5	9	13	11	13	1,352,090	2,643,485	3,435,360	3,007,505	3,435,360	0.44	0.86	1.12	0.98	1.12

2026	4	313,216,036	16,208,279	122,201,131	7	14	21	17	21	2,541,764	4,906,639	6,875,209	5,797,042	6,875,209	0.81	1.57	2.20	1.85	2.20
2027	5	318,637,972	16,488,853	138,689,984	11	20	32	25	32	4,304,809	8,173,359	12,218,234	9,992,214	12,218,234	1.35	2.57	3.83	3.14	3.83
2028	6	324,153,765	16,774,283	155,464,267	15	27	45	35	45	6,802,611	12,648,066	19,839,013	15,903,864	19,839,013	2.10	3.90	6.12	4.91	6.12
2029	7	329,765,038	17,064,655	172,528,922	20	34	59	46	59	10,218,460	18,519,724	29,871,363	23,759,988	29,871,363	3.10	5.62	9.06	7.21	9.06
2030	8	335,473,446	17,360,053	189,888,976	26	43	71	57	71	14,747,196	25,936,956	42,164,012	33,647,872	42,164,012	4.40	7.73	12.57	10.03	12.57
2031	9	341,280,670	17,660,565	207,549,541	33	51	80	67	80	20,578,344	34,986,358	56,366,157	45,496,860	56,366,157	6.03	10.25	16.52	13.33	16.52
2032	10	347,188,420	17,966,279	225,515,819	41	60	87	76	87	27,874,574	45,681,146	72,067,840	59,110,758	72,067,840	8.03	13.16	20.76	17.03	20.76
2033	11	353,198,436	18,277,285	243,793,104	49	67	92	83	92	36,750,158	57,963,965	88,904,681	74,228,851	88,904,681	10.40	16.41	25.17	21.02	25.17
2034	12	359,312,488	18,593,674	262,386,778	57	74	95	88	95	47,255,587	71,722,264	106,599,540	90,584,506	106,599,540	13.15	19.96	29.67	25.21	29.67
2035	13	365,532,378	18,915,541	281,302,319	64	80	97	92	97	59,373,358	86,810,274	124,961,024	107,942,892	124,961,024	16.24	23.75	34.19	29.53	34.19

2036	14	371,859,938	19,242,979	300,545,297	71	85	98	94	98	73,025,988	103,070,847	143,865,031	126,116,276	143,865,031	19.64	27.72	38.69	33.91	38.69
2037	15	378,297,031	19,576,085	320,121,382	77	88	99	96	99	88,092,962	120,352,474	163,234,685	144,964,202	163,234,685	23.29	31.81	43.15	38.32	43.15
2038	16	384,845,554	19,914,957	340,036,339	82	91	99	98	99	104,430,944	138,519,886	183,024,274	164,386,458	183,024,274	27.14	35.99	47.56	42.71	47.56
2039	17	391,507,435	20,259,696	360,296,035	86	93	100	98	100	121,892,040	157,458,883	203,207,959	184,314,138	203,207,959	31.13	40.22	51.90	47.08	51.90
2040	18	398,284,636	20,610,402	380,906,437	89	95	100	99	100	140,337,128	177,077,054	223,772,322	204,701,420	223,772,322	35.24	44.46	56.18	51.40	56.18
2041	19	405,179,155	20,967,179	401,873,616	92	96	100	99	100	159,643,669	197,302,079	244,711,631	225,518,931	244,711,631	39.40	48.70	60.40	55.66	60.40
2042	20	412,193,022	21,330,132	423,203,747	94	97	100	100	100	179,708,884	218,078,941	266,024,898	246,748,789	266,024,898	43.60	52.91	64.54	59.86	64.54

Table 29: Virtual Mirror (UC3) Adoption Projection

					% of new vehicles which are connected (%)					Cumulative number of vehicles which are connected (Qty)					Connected Vehicle Density (Percentage)				
Year	Our Analysis Year	Total Vehicles in Use	Of which are new	Cummulative new	Market Scenario 1	Market Scenario 2	Market Scenario 3	Market Scenario 4	Market Scenario 5	Market Scenario 1	Market Scenario 2	Market Scenario 3	Market Scenario 4	Market Scenario 5	Market Scenario 1	Market Scenario 2	Market Scenario 3	Market Scenario 4	Market Scenario 5

2018	-	273,033,330																	
2019	-	277,759,682	14,373,486	14,373,486															
2020	-	282,567,850	14,622,299	28,995,785															
2021	-	287,459,249	14,875,418	43,871,203															
2022	-	292,435,322	15,132,920	59,004,123	-	-	-	-	-	-	-	-	-	-					
2023	1	297,497,532	15,394,879	74,399,002	4	3	4	3	4	585,877	393,513	585,877	393,513	585,877	0.20	0.13	0.20	0.13	0.20
2024	2	302,647,373	15,661,372	90,060,374	10	7	10	7	10	2,096,801	1,422,937	2,096,801	1,422,937	2,096,801	0.69	0.47	0.69	0.47	0.69
2025	3	307,886,360	15,932,479	105,992,853	18	13	18	13	18	4,980,213	3,435,360	4,980,213	3,435,360	4,980,213	1.62	1.12	1.62	1.12	1.62
2026	4	313,216,036	16,208,279	122,201,131	29	21	29	21	29	9,733,635	6,875,209	9,733,635	6,875,209	9,733,635	3.11	2.20	3.11	2.20	3.11
2027	5	318,637,972	16,488,853	138,689,984	43	32	43	32	43	16,770,950	12,218,234	16,770,950	12,218,234	16,770,950	5.26	3.83	5.26	3.83	5.26

2028	6	324,153,765	16,774,283	155,464,267	57	45	57	45	57	26,266,413	19,839,013	26,266,413	19,839,013	26,266,413	8.10	6.12	8.10	6.12	8.10
2029	7	329,765,038	17,064,655	172,528,922	69	59	69	59	69	38,089,881	29,871,363	38,089,881	29,871,363	38,089,881	11.55	9.06	11.55	9.06	11.55
2030	8	335,473,446	17,360,053	189,888,976	79	71	79	71	79	51,886,809	42,164,012	51,886,809	42,164,012	51,886,809	15.47	12.57	15.47	12.57	15.47
2031	9	341,280,670	17,660,565	207,549,541	87	80	87	80	87	67,229,128	56,366,157	67,229,128	56,366,157	67,229,128	19.70	16.52	19.70	16.52	19.70
2032	10	347,188,420	17,966,279	225,515,819	92	87	92	87	92	83,732,737	72,067,840	83,732,737	72,067,840	83,732,737	24.12	20.76	24.12	20.76	24.12
2033	11	353,198,436	18,277,285	243,793,104	95	92	95	92	95	101,105,608	88,904,681	101,105,608	88,904,681	101,105,608	28.63	25.17	28.63	25.17	28.63
2034	12	359,312,488	18,593,674	262,386,778	97	95	97	95	97	119,147,120	106,599,540	119,147,120	106,599,540	119,147,120	33.16	29.67	33.16	29.67	33.16
2035	13	365,532,378	18,915,541	281,302,319	98	97	98	97	98	137,728,175	124,961,024	137,728,175	124,961,024	137,728,175	37.68	34.19	37.68	34.19	37.68
2036	14	371,859,938	19,242,979	300,545,297	99	98	99	98	99	156,769,481	143,865,031	156,769,481	143,865,031	156,769,481	42.16	38.69	42.16	38.69	42.16
2037	15	378,297,031	19,576,085	320,121,382	99	99	99	99	99	176,224,312	163,234,685	176,224,312	163,234,685	176,224,312	46.58	43.15	46.58	43.15	46.58

2038	16	384,845,554	19,914,957	340,036,339	100	99	100	99	100	196,066,489	183,024,274	196,066,489	183,024,274	196,066,489	50.95	47.56	50.95	47.56	50.95
2039	17	391,507,435	20,259,696	360,296,035	100	100	100	100	100	216,282,542	203,207,959	216,282,542	203,207,959	216,282,542	55.24	51.90	55.24	51.90	55.24
2040	18	398,284,636	20,610,402	380,906,437	100	100	100	100	100	236,866,789	223,772,322	236,866,789	223,772,322	236,866,789	59.47	56.18	59.47	56.18	59.47
2041	19	405,179,155	20,967,179	401,873,616	100	100	100	100	100	257,818,298	244,711,631	257,818,298	244,711,631	257,818,298	63.63	60.40	63.63	60.40	63.63
2042	20	412,193,022	21,330,132	423,203,747	100	100	100	100	100	279,139,045	266,024,898	279,139,045	266,024,898	279,139,045	67.72	64.54	67.72	64.54	67.72

Table 30: Cross Border (UC4) Adoption Projection

					% of new vehicles which are connected (%)					Cummulative number of vehicles which are connected (Qty)					Connected Vehicle Density (Percentage)				
Year	Our Analysis Year	Total Vehicles in Use	Of which are new	Cummulative new	Market Scenario 1	Market Scenario 2	Market Scenario 3	Market Scenario 4	Market Scenario 5	Market Scenario 1	Market Scenario 2	Market Scenario 3	Market Scenario 4	Market Scenario 5	Market Scenario 1	Market Scenario 2	Market Scenario 3	Market Scenario 4	Market Scenario 5
2018	-	273,033,330																	
2019	-	277,759,682	14,373,486	14,373,486															

2020	-	282,567,850	14,622,299	28,995,785															
2021	-	287,459,249	14,875,418	43,871,203															
2022	-	292,435,322	15,132,920	59,004,123	-	-	-	-	-	-	-	-	-	-					
2023	1	297,497,532	15,394,879	74,399,002	4	4	4	4	4	585,877	585,877	585,877	585,877	585,877	0.20	0.20	0.20	0.20	0.20
2024	2	302,647,373	15,661,372	90,060,374	10	10	10	10	10	2,096,801	2,096,801	2,096,801	2,096,801	2,096,801	0.69	0.69	0.69	0.69	0.69
2025	3	307,886,360	15,932,479	105,992,853	18	18	18	18	18	4,980,213	4,980,213	4,980,213	4,980,213	4,980,213	1.62	1.62	1.62	1.62	1.62
2026	4	313,216,036	16,208,279	122,201,131	29	29	29	29	29	9,733,635	9,733,635	9,733,635	9,733,635	9,733,635	3.11	3.11	3.11	3.11	3.11
2027	5	318,637,972	16,488,853	138,689,984	43	43	43	43	43	16,770,950	16,770,950	16,770,950	16,770,950	16,770,950	5.26	5.26	5.26	5.26	5.26
2028	6	324,153,765	16,774,283	155,464,267	57	57	57	57	57	26,266,413	26,266,413	26,266,413	26,266,413	26,266,413	8.10	8.10	8.10	8.10	8.10
2029	7	329,765,038	17,064,655	172,528,922	69	69	69	69	69	38,089,881	38,089,881	38,089,881	38,089,881	38,089,881	11.55	11.55	11.55	11.55	11.55

2030	8	335,473,446	17,360,053	189,888,976	79	79	79	79	79	51,886,809	51,886,809	51,886,809	51,886,809	51,886,809	15.47	15.47	15.47	15.47	15.47
2031	9	341,280,670	17,660,565	207,549,541	87	87	87	87	87	67,229,128	67,229,128	67,229,128	67,229,128	67,229,128	19.70	19.70	19.70	19.70	19.70
2032	10	347,188,420	17,966,279	225,515,819	92	92	92	92	92	83,732,737	83,732,737	83,732,737	83,732,737	83,732,737	24.12	24.12	24.12	24.12	24.12
2033	11	353,198,436	18,277,285	243,793,104	95	95	95	95	95	101,105,608	101,105,608	101,105,608	101,105,608	101,105,608	28.63	28.63	28.63	28.63	28.63
2034	12	359,312,488	18,593,674	262,386,778	97	97	97	97	97	119,147,120	119,147,120	119,147,120	119,147,120	119,147,120	33.16	33.16	33.16	33.16	33.16
2035	13	365,532,378	18,915,541	281,302,319	98	98	98	98	98	137,728,175	137,728,175	137,728,175	137,728,175	137,728,175	37.68	37.68	37.68	37.68	37.68
2036	14	371,859,938	19,242,979	300,545,297	99	99	99	99	99	156,769,481	156,769,481	156,769,481	156,769,481	156,769,481	42.16	42.16	42.16	42.16	42.16
2037	15	378,297,031	19,576,085	320,121,382	99	99	99	99	99	176,224,312	176,224,312	176,224,312	176,224,312	176,224,312	46.58	46.58	46.58	46.58	46.58
2038	16	384,845,554	19,914,957	340,036,339	100	100	100	100	100	196,066,489	196,066,489	196,066,489	196,066,489	196,066,489	50.95	50.95	50.95	50.95	50.95
2039	17	391,507,435	20,259,696	360,296,035	100	100	100	100	100	216,282,542	216,282,542	216,282,542	216,282,542	216,282,542	55.24	55.24	55.24	55.24	55.24

2040	18	398,284,636	20,610,402	380,906,437	100	100	100	100	100	236,866,789	236,866,789	236,866,789	236,866,789	236,866,789	59.47	59.47	59.47	59.47	59.47
2041	19	405,179,155	20,967,179	401,873,616	100	100	100	100	100	257,818,298	257,818,298	257,818,298	257,818,298	257,818,298	63.63	63.63	63.63	63.63	63.63
2042	20	412,193,022	21,330,132	423,203,747	100	100	100	100	100	279,139,045	279,139,045	279,139,045	279,139,045	279,139,045	67.72	67.72	67.72	67.72	67.72

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