Viktor Simon De Naeyer

Implementing Cooperative Intelligent Transportation Systems: A Maturity Model for Assessing the Readiness of Cities

Master Thesis

at the Chair for Information Systems and Information Management
(Westfälische Wilhelms-Universität, Münster)

Supervisor: Dr. Michael Räckers

Presented by: Viktor Simon De Naeyer
Schlossplatz 2
48149 Münster
+49 251 8338100
vdenaeye@uni-muenster.de

Date of Submission: 2021-08-09

Content

Figures

Tables

Abbreviations

5G	Fifth generation of cellular networks
AI	Artificial Intelligence
AV	Automated Vehicle
BPMN	Business Process Model and Notation
CCAM	Cooperative Connected and Automated Mobility
CISMOB	Cooperative information platform for low carbon and sustainable mobility
C-ITS	Cooperative Intelligent Transportation Systems
CMM	Capability Maturity Model
CMMI	Capability Maturity Model Integration
CV	Connected Vehicle
DG MOVE	Directorate-General for Mobility and Transport
DSRM	Design Science Research Methodology
EC	European Commission
ETSI	European Telecommunication and Standardisation Institute
EU	European Union
GDP	Gross Domestic Product
GLOSA	Green Light Optimal Speed Advisory
GPS	Global Positioning System
IoT	Internet of Things
$ITPM^3$	IT Performance Measurement Maturity Model
ITS	Intelligent Transportation Systems
KMCA	Knowledge Management Capability Assessment
LTE	Long Term Evolution
MaaS	Mobility as a Service
NPM	New Public Management
OBU	On board Unit
RSU	Road Side Unit
SCMAB	Smart City Maturity Assessment and Benchmarking
SUMPS	Sustainable Urban Mobility Plans
TSMO CMM	Transportation Systems Management and Operations Capability Maturity Model
UMP	Urban Mobility Plan
USDOT	United States Department of Transportation
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle to Everything

1 Introduction

The development of transportation has continuously allowed people to reach more distant destinations and take on new opportunities. It touches almost everyone on a daily basis, from doing groceries to going to work. Consequently, transportation developments have been critical in the creation of economically and socially vibrant areas, generating income and wealth for their citizens, clustering skilled people, opening new horizons for professional specialisations and in general making distant locations closer (Browne & Ryan, 2011; Moore & Pulidindi, 2011). However, experts have been warning for years that the increasing use of transportation systems has been approaching its limits, negatively affecting the environment and its users. The transportation field is facing several challenges as the transport sector contributes 23% of global energy-related greenhouse gas emissions, congestions and other traffic inefficiencies have a significant economic toll estimated to up to 8% of GDP, and accidents, air and noise pollution negatively affect human health (World Bank, 2021). The ecological impact and human toll has been forcing society to rethink how people can continue benefiting from these perks in a sustainable way.

The problematic has been widely recognised and has become a main priority for urban areas across the world as they face many challenges. European cities have seen a steady increase of their populations expecting 80% of citizens to live in cities by 2050, while more than 80% of economic growth and employment is also located within these crowded spaces (European Commission, 2017). Due to this high concentration of activity and various transportation challenges, cities are being put forward to take action and lead change to a more sustainable transportation system (International Transport Forum, 2021). However, conventional ways such as building additional links in the transportation network have found to be insufficient for solving the problem, on the contrary, research has shown that this leads to more traffic often referred to as the induced demand effect (Dudley & Preston, 2013). Therefore, city authorities are looking to new solutions, exploring innovations that can lead the move to more sustainable urban mobility.

Amongst several developments in sustainable transportation, the coming together of the transportation field and innovations in sensor and communication technologies has allowed transport systems to become more intelligent. This has given rise to Cooperative Intelligent Transport Systems (C-ITS), a next step in Intelligent Transport Systems (ITS), that source and exchange previously unavailable information between road users and the road infrastructure. C-ITS services take shape in a diverse number of applications and are expected to make transport more efficient, comfortable, secure and environmentally friendly. Therefore, the European Commission released a European strategy on C-ITS in

2016 as a milestone towards cooperative, connected and automated mobility (CCAM). The goal of this strategy was to ensure the coordinated and swift deployment of C-ITS, and maximise the benefits from this digitalisation. This strategy includes a list of several Day 1 C-ITS services that would be ready for large scale deployment in 2019 and an additional number of services that should be considered mature around that time as well. As such, the development of C-ITS throughout Europe is being promoted with several projects focussing on urban areas as they are on the frontline position to make transportation more sustainable (International Transport Forum, 2021).

However, the widescale adoption of C-ITS has been limited and has been taking place in an unbalanced way across Europe with many cities lagging behind (Lu et al., 2019). Researchers have been putting forward several challenges for the deployment of C-ITS that hamper a swift implementation in urban areas including high investment costs, heterogenous cities, a low penetration grade of the technologies, legacy infrastructure, privacy concerns and a lack of organisational capabilities (Asselin-Miller et al., 2016; C-ITS Platform, 2017; Proskawetz et al., 2013). While research in this field has been strongly developing the technical side of C-ITS services, knowledge gaps exist on the implementation challenges of city authorities (Ricci & George, 2014). The initiative and execution of these projects are often carried by city authorities as they are responsible for these territories and they help in making transport more sustainable. City authorities and other stakeholders involved have been emphasising the challenges for successfully implementing these services which go beyond the technical barriers, and are crucial for how these services will be realised. As such, the C-ITS platform phase I report (2017) suggested that research should not only ask "is C-ITS ready for cities?", but also "are cities ready for C-ITS?"

In order to provide an answer to the latter question, and support city authorities in the operationalisation of C-ITS services an assessment method is required. While a number of publications have already developed indicators, rankings and benchmarks to evaluate urban development outcomes, enabling the competitive positioning of cities, few have focussed on assessing the preparedness of a city in implementing innovative transport technologies and providing guidance to improve this (Warnecke et al., 2018). However, in many fields maturity models have been put forward as a tool for organisations to continuously assess and compare a specific area, providing a suggested path to follow (Becker et al., 2009). While the use of these models is still in its infancy in the transportation field, it is seen as the ideal tool to help cities assess the current maturity of their transportation system, and exchange their experience with their counterparts (Charles et al., 2011; Houghton et al., 2009).

Therefore, the goal of this research is to develop a maturity model for practitioners that assesses the city's current environment for implementing C-ITS technologies. This tool would allow cities to identify their main strengths and weaknesses, provide guidance to attain a higher level of maturity by setting out next steps, and allow for the comparison with other cities which would help in exchanging best practices. The outcome of this research is to support authorities in future investments and create a better understanding of the needs and possible next steps in C-ITS development. As such it would help support the swift implementation of C-ITS services set out in the C-ITS strategy, and enable a more holistic development across Europe.

To guide the development of this maturity model, a design science approach is taken based on the process by Peffers et al. (2007). As a first step, the research background is discussed in the next chapter, providing insights in the current state of the researched field and introduce the underlying technologies and related problematic. In the third chapter, research on C-ITS deployment and the broader smart city field is aggregated to provide an overview of the current state of the field and identify knowledge gaps that need to be addressed. The maturity model development method is subsequently defined based on specific insights from the standardised maturity model development frameworks by Becker et al. (2009) and de Bruin et al. (2005). The fifth chapter addresses the design of the maturity model, considering other relevant maturity models and best practices and challenges identified for the implementation of C-ITS in urban areas. This model is then evaluated by experts through interviews with the results of this described in the seventh chapter. Insights on the proposed maturity model are then discussed in the subsequent chapter, providing recommendations for the further development of the maturity model. Concluding, the final chapter aggregates the insights from this research and suggest next steps for research in this field.

2 Research Background

With the seemingly unrelenting increase of private car ownership and freight transport, many researchers have expanded their focus to how transportation affects other systems as well (Dudley & Preston, 2013). It has been shown that the current transportation systems come with several negative effects on the environment such as by the burning fossil fuels emitting carbon dioxide; noise pollution; on security, numerous fatal accidents every year; and congestions worldwide leading to a loss of time, fuel and productivity of travellers (European Commission, 2007; Moore & Pulidindi, 2011; OECD, 2002). In densely populated areas these issues are even more challenging (Mozos-blanco et al., 2018). In the case of the EU for example, in 2010, 73% of the population lived in urban areas which are also a major source of activity with around 85% of the EU's GDP being created there (European Commission, 2017). This puts these crowded areas at the centre of activity

The problematic side associated with transportation has taken an increasingly important role in shaping the public debate and government policies, shifting their focus to sustainable transport (Bray et al., 2011). Dudley and Preston (2013), noted the importance of such changes on transport studies, stating that: "the evolving technological, economic, political, and social context inevitably has had a powerful and pervasive influence over the trajectory and character of the subject." Consequently, a big part of transportation research has committed itself to curb these negative external effects, based on the evolving contexts underlying transport research. Especially academic disciplines such as engineering, economics, psychology and mathematics have helped develop new solutions for transportation issues (Marsden & Reardon, 2017).

Attempts to solve transportation issues have been moving away from the conventional demand driven solutions, such as building more roads, as they have been proven ineffective (Dudley & Preston, 2013). Now, technological innovations, and the role of human behaviour has taken a central in a the transportation field with research looking at changing human behaviour by for example (flexible) road pricing, dissuading people to drive at certain peak hours. Giannopoulos and Munro (2019), speak of a transport revolution, conceptualised as "the punctuated confluence of a broad array of innovations—based on fundamental progress or parallel maturation—in various disciplines". The transport sector has already embraced many of these innovations and the need for safer more efficient and sustainable transport (European Commision, 2016). New technologies have led to the creation of new business models for ride or car sharing that promote more sustainable behaviour. Also greener vehicles have become more popular with electrical vehicles taking off. Other ideas are looking to change the broader transportation system such as with Mobility as a Service (MaaS), which wants to provide a centralised multimodal mobility offer.

In their book Giannopoulos and Munro (2019) list six technological innovations that will define the mid-21st century transportation systems. This view is supported by several authors, especially about the promising nature of communications technologies (Nijkamp, 2006; Scholliers et al., 2017; Zhao et al., 2020). It is important to note that these are not just ideas for the future anymore, but they are being developed world wide for large scale implementation (Lu et al., 2018). However, with these new developments experts argue there is also a need to modify the current transport research agenda (Ricci & George, 2014). Research has found that the majority of literature on technological innovation is based on natural sciences, taking a positivist orientation. Not only should promising technologies be further researched, but there should be looked beyond the technology, to the broader system, policy interests, conceptual changes but also new data sources and methodological opportunities (Ibid.). Additionally, the importance of multidisciplinary research is critical because of the broad implications transportation has (Dudley & Preston, 2013).

Marsden & Reardon, (2017) emphasise the need for more multidisciplinary research and critique the often positivist-led approach in transportation research. Rather, an important third element to the transport field needs to be considered in this evolution, namely the public policy side (Allsop, 2006). When considered in transportation research, the role of public authorities strongly depend on the literature stream. The main research stream considers the important role authorities have as a policy creator, to design policies that tackle the challenges in transportation. However, governments also play a more undertaking role in research studying technological innovations in the transportation sector, as an investor and regulator (Giannopoulos & Munro, 2019). Additionally, in many cases the public sector also plays a major role as public transport provider, which is important for research on more sustainable transport systems or multimodal transport solutions. Lastly, public authorities are often responsible for managing and maintaining public infrastructure such as roads and everything around it, in order to create safe traffic situations.

The transport revolution, has therefore provided the public sector with new tools to take on negative effects from transportation, but also provided new challenges in implementing them. All the parts of transportation systems are becoming more intelligent and interconnected, often meaning creating a digital layer to the existing infrastructure making this a key area of innovation while the different responsibilities are becoming more integrated (Munhoz et al., 2020). A crucial field that has seen big developments in the last decades is that of Intelligent Transportation Systems (ITS), which is based on "intermeshing digital technologies amongst devices, vehicles, and infrastructure for better traffic management." (International Transport Forum, 2021). The increased intelligence of transportation is driven by the increase of information that is being sourced, with new sensors and telecommunications, and the increase in information processing and control technology that can use this information to act on it (Lu et al., 2018). While this development has been happening for some years, a more recent step has been set in the direction of creating Cooperative Intelligent Transportation Systems (C-ITS), leveraging new innovations in communications technologies to help tackle the challenges transportation systems are facing (Asselin-Miller et al., 2016).

2.1 C-ITS

C-ITS also known as "connected vehicle technology" (CV technology), is a subset of the overall ITS and is often regarded as the next step in these systems (ESCAP, 2017). C-ITS distinguishes itself by allowing for direct sharing of information between vehicles (V2V), road infrastructure (V2I) and other road users such as pedestrians or cyclists (V2X) (Sjöberg et al., 2017). Özel and Bläsche (2019), describe it as: "a holistic, control, information and communication upgrade to traditional transport and traffic systems" or in a more straightforward way Proskawetz et al. (2013), describe the evolution as after having learned how to "feel" (by sensors), and "see" (by cameras), C-ITS allows transportation systems to "speak" (by communication systems). In such a system, road users exchange previously unavailable information through different channels in order to coordinate or guide movements. For some applications, these innovations are seen as complementary to the existing ITS infrastructure, providing a similar functionality but with a greater performance, however, there are also opportunities where it provides an alternative solution to currently used technologies or even creates new functionalities (Hadi et al., 2019).

This exchange of information makes use of wireless communication technologies, and recent developments in in-vehicle communication systems and the broad adoption of mobile phones. A dedicated short range radio frequency ETSI ITS-G5 allows transmitters to send messages with low latencies, while cellular based communication technologies such as LTE or 3/4/5G allow for a long range exchange of information (Blokpoel, 2019). As such, a network of different hardware components that are used by the components of a transportation system support C-ITS services which provide specific functionalities to the user. Services with various functionalities are being developed based on these technologies, constantly developing new applications. Regarding C-ITS systems, four types of sub-systems are distinguished that make up the communications architecture (Asselin-Miller et al., 2016; Sun et al., 2016):

1. In-vehicle ITS sub-system or On Board Unit (OBU) are fitted in the vehicle by the manufacturer or retrofitted to the vehicle. These technologies enable V2V and V2I communications.

2. Personal ITS sub-systems are defined as hand-held devices that are not attached to a vehicle's information bus such as personal navigation systems, tablets and mobile phones. These technologies allow for V2I communications and are expected to also allow for V2V communication in the future when the technical barriers can be overcome such as transmission delay and overflow of messages.

3. Infrastructure ITS sub-systems or Road Side Units (RSU) and sensors can be installed along roads. They form the basis of V2I communication and need to be installed and maintained by the relevant authority.

4. Lastly, the central ITS sub-system is the equipment operated by entities that are responsible for multiple ITS applications. They can use this central system to monitor, maintain and provide services to users.

To bring this to the users, several C-ITS services can be combined as a bundle in one application. These bundles differ between the various end user types which include drivers or individual users of the road network, vulnerable road users, public transportation fleets' operators, commercial fleets' operators and emergency services vehicles (Mitsakis et al., 2020). Additionally, C-ITS services can also be bundled for traffic management, exploiting the usability of these services to optimise the network use and regulate services (Ibid.). This end product is relevant for road operators or traffic managers to identify problems and execute their responsibilities, and for service providers to offer this information to their in-car information service, such as when a green light will be on or off, and end-users in general for mode and trip advice (Ibid.). This implementation of C-ITS should allow for flexibility, and cost efficiency.

According to researchers, these technologies are expected to create several positive effects, supporting transport policy. Firstly, it will help improve road safety, extending the vision of vehicles beyond the line-of-sight of the driver or the sensors of the vehicle. Secondly, it will increase traffic efficiency by coordinating the actions of road users improving road capacity (Vannieuwenborg et al., 2019). Indirectly, this will also decrease the environmental impact of driving, by decreasing the negative external effects associated with congestions such as inefficient fuel usage and increased emissions (Özel

& Bläsche, 2019). Thirdly, it will increase driving comfort by helping the driver take decisions and provide information on the traffic situation (European Commision, 2016). Even papers that critique the reliance on technology, which is unlikely to solve the underlying structural problems in transportation, do acknowledge the initial benefits it could bring (Hensher, 2018). Due to the these promising effects and the focus on sustainable transport systems mentioned before, there is a high interest in developing and implementing these technologies.

C-ITS projects are being developing around the world and have gotten particularly strong attention in the US, EU and Japan (Alam et al., 2016). Up until 2017 both the US and EU spent more than 700 million euros in funding on more than sixty individual projects in the latter and fourteen in the former respectively (Kotsi et al., 2020). In the EU, the European Commission has taken an important role in the development of C-ITS starting in 2005 with supporting projects on cooperative systems, and has continued focussing on the deployment across EU countries (Lu et al., 2018). Consequently, as this digitalisation was taking off in countries such as the USA, Australia, China, Korea and Japan and several stakeholders were asking for action the European Commission established a European strategy on C-ITS in 2016. This strategy was developed to speed-up the development of C-ITS, and ensure coordination on a European level, create synergies between projects and develop an interoperable system (European Commision, 2016).

Importantly, the directive they have put forward has established a legal framework for C-ITS projects across Europe enabling these goals. The eventual focus of this strategy is to increase the intelligence of transport systems and extend the context of C-ITS to enabling cooperative, connected and automated mobility (CCAM) (Lu et al., 2018). C-ITS can be seen as a vital stepping stone in the drive for automated vehicles, as research has found that automated mobility without connectivity could deteriorate traffic conditions, rather than improve them (Vannieuwenborg et al.,2019). Moreover, the C-ITS platform and C-roads initiatives were established to foster a common vision within Europe, and to deploy large-scale projects across several countries. These initiatives stimulate the gathering of experience and knowledge sharing between pilot sites, and pioneered cross-border deployment.

Based on these initiatives, the Commission identified 20 services shown in table 1 of which several Day 1 services should be mature in 2019 and were expected to be deployed broadly. In the C-ITS platform report (2017) and the study procured by DG MOVE on the deployment of C-ITS in Europe (2016) the progress in this field was broadly discussed with input from several stakeholders. Both of these reports identified a divide between services that will be mainly applicable for either highway transport or urban areas. For example, services related to in-vehicle weather conditions or road works warnings are seen as specifically useful for highway transport, while services related to dynamic parking and traffic lights, such as GLOSA or priority requests are seen as most relevant for urban services, because urban areas contain most traffic lights and emergency vehicles or public transport would benefit from a smoother flow through crowded urban traffic (Asselin-Miller et al., 2016).

Table 1. List of Day 1 and Day 1.5 C-ITS services

Day 1 C-ITS services list	Day 1.5 C-ITS services list
Hazardous location notifications o Slow or stationary vehicle(s) & traffic ahead warning o Road works warning o Weather conditions o Emergency brake light o Emergency vehicle approaching o Other hazards	o Information on fuelling & charging stations for alternative fuel vehicles; o Vulnerable road user protection; o On street parking management & information; o Off street parking information; o Park & ride information; o Connected & cooperative navigation into and out of the city o Traffic information & smart routing.
Signage applications o In-vehicle signage o In-vehicle speed limits o Signal violation / intersection safety o Traffic signal priority request o Green light optimal speed advisory (GLOSA) o Probe vehicle data o Shockwave damping	

c.f. European Commission., (2016)

2.2 C-ITS in urban areas

As has become clear from the reports by the European Commission, several C-ITS services would be specifically useful within urban areas and are expected to be mature in

2019. As such, the interest of cities in methods that help improve traffic in these crowded areas is significant. Specifically for the case of Europe, this area holds a high number of medium and large cities struggling with the increasing burden on urban transport networks (C-ITS Platform, 2017).

The experience of mobility differs between the landscape of urban areas, which in turn results in different needs and expectations that need to be attained by C-ITS services. Initiatives have been bringing city authorities together by creating working groups in which they exchange information, put forward their needs and cooperate on projects in order to shape these technologies for the needs of their urban transportation systems (C-ITS Platform, 2017). Larger urban areas experience a higher density and crowding which comes with specific challenges such as congestion, sub-standard living conditions, crime, and inequity while smaller communities are more concerned with the access to opportunity requiring an efficient transportation system that reaches economically active areas (International Transport Forum, 2020). Moreover, a major heterogeneity exists between urban transportation challenges between developing and developed cities (Dimitriou & Gakenheimer, 2011). This needs to be considered when taking on challenges in these different contexts, consequently, this research will focus on the European situation in order to ensure its relevance for these urban areas and the specific developments in C-ITS.

Several papers on the urban application of C-ITS frame this within the “intelligent” or “smart” city literature (often used interchangeably), where these intelligent cities are driven by and build on technological innovations such as C-ITS which allow the infrastructure and services of cities to become more intelligent, interconnected and efficient (Munhoz et al., 2020; Zhang et al., 2020). Within the smart city move, these transportation innovations are often aggregated under smart mobility and are only of one of several aspects of a smart city also including smart economy, smart people, smart governance, smart environment and smart living according to the definition by Giffinger et al. (2007). However, smart mobility is argued to be one of the largest sources of data in smart cities and is built on ICT, founded in ITS and subsequent C-ITS applications (Kim et al., 2015; Tafidis & Bandeira, 2017). Therefore, a large role can be attributed to this aspect and the underlying ITS and C-ITS services. These new sources of information can be collected and processed, supporting services that can be integrated in transport infrastructure and subsequently creating applications that can influence traffic creating new opportunities for city authorities.

Local authorities play a key role here especially in large cities where urban transport responsibilities include, the planning and development of transport infrastructure, management of roads and road use, public transport organisation, development and regulation, financing and investment, and being an interface with land use and urban planning (Meakin, 2004). These public organisations play an important role in transport, but the involvement and expected benefits can vary widely between organisations (Ricci & George, 2014). Nevertheless, these contexts can benefit strongly from the promise of using existing infrastructure more efficiently to create more sustainable urban transportation networks, however, their active participation is required in building smart mobility (Munhoz et al., 2020). Research has found that the responsibility for smart mobility initiatives usually falls on the shoulders of city authorities as they also overlap with the goals of these authorities, and are deployed on their territories (International Transport Forum, 2020). For this reason, many cities want to guide the development of C-ITS and other smart mobility technologies. In order to support the deployment of C-ITS services, cities, under which is understood, all those partners belonging to the decision making and road management activities for an urban geographical area, are required to keep up and adapt to these innovations (Lu et al., 2019).

However, there are still several challenges remaining that form barriers to the widescale deployment of C-ITS services. Firstly, for C-ITS services to be considered useful enough road users need to be equipped with the right communication technologies, however, this penetration grade is expected to only slowly pick up with the replacement of older vehicles (Lu et al., 2018). Therefore, city authorities are cautious to implement these novel services as returns might take time. Related with this challenge is the high cost that these new technologies bring with them. Asselin-Miller et al. (2016) argue that urban transport authorities will have to carry a significant part of the investment costs for the deployment of C-ITS. Specifically, investments in installing the required technologies on the existing backbone infrastructure can become expensive. Additionally, these C-ITS services need to be adapted to the specific historical, geographic, demographic and cultural context of the urban area, which creates more challenges (International Transport Forum, 2020).

Additionally, in order to make cities suitable for C-ITS deployment changes in the management structure of urban transportation, communication between systems, the existing backbone infrastructure and the know-how need to happen (Proskawetz et al., 2013). An additional challenge is that this needs to be applied to heterogenous entities with different sizes, strongly different management structures and needs, and historical, geographic, demographic and cultural context creating several barriers to the deployment of C-ITS in urban areas (C-ITS Platform, 2017; Kaparias et al., 2010).

While, research is developing strongly on the technical side of these innovations, it is less focused on the organisational side in transportation systems and the challenges related to the role of the public sector and city authorities (Ongkittikul & Geerlings, 2006). Research has found that the heterogenous cities, which exist of various entities, with different sizes, strongly different management structures and different levels of expertise create barriers to the deployment of C-ITS in urban areas (C-ITS Platform, 2017; Kaparias et al., 2010). Subsequently, in order to make cities suitable for C-ITS deployment changes in the management structure of urban transportation, communication between systems, the existing backbone infrastructure and the know-how need to happen (Proskawetz et al., 2013). The C-ITS Platform Phase II report (2017) summarises this in one basic question that needs to be addressed "are cities ready for C-ITS or is C-ITS ready for cities?" While the response to the latter part of the question has been strongly developed in recent years, the former question is equally important “are cities ready for C-ITS?”. Lu et al. (2019) note the heterogeneity in this across Europe, seeing an unbalanced development and deployment of C-ITS.

Learning from previous urban ITS and C-ITS experiences should be stimulated for all stakeholders in order to support wide deployment, allowing for the greatest benefits (C-ITS Platform, 2017). The need for this can be very well illustrated by the various platforms that have been created to develop C-ITS knowledge, and city networks that are actively exchanging experiences between members. Moreover, as part of the C-Mobile project, generalised guidelines for cities were developed to assist in the deployment of C-ITS services and take on the unbalanced development between cities (Lu et al., 2019). Therefore, it is crucial to go beyond the technical side and study the interdisciplinary facets of transportation research, in order to understand how these fundamental technological development changes where city authorities stand, and how they could improve managing this change (Marsden & Reardon, 2017; Ricci & George, 2014).

2.3 Maturity models

Because organisations need to continuously adapt to change and take stock of their current capabilities, tools have been developed to support organisations such as city authorities in this endeavour. Maturity models have been designed as an evaluative and comparative basis for improvement of a specific area of an organisation (De Bruin et al., 2005). In the search for an explanation of what maturity models are, Wendler (2012) employs the explanation by Becker et al. (2009) defining it as:

‘‘A maturity model consists of a sequence of maturity levels for a class of objects. It represents an anticipated, desired, or typical evolution path of these objects shaped as discrete stages. Typically, these objects are organizations or processes.’’

These models are based on the assumption of predictable patterns of organizational evolution concerning the aspect that is being researched (Plattfaut et al., 2011). Maturity models visualise this evolution of an organisation along a stage-by-stage process (Röglinger et al., 2012). These stages are sequential in nature, represent a hierarchical progress which is hard to reverse, and involve the broad organisation and structure (Gottschalk, 2009). Different stages of maturity get identified by assigning specific levels of individual criteria to them, taking into account the multidimensionality of the issue (Becker et al., 2009). The organisation can then identify the maturity of their process, technology or capacities by assessing the performance for each individual indicator and aggregating them by the predefined rules of the model. Based on the perspective of the model on growth the goal is either to attain, the final perfect stage through an organisational evolution (life cycle approach), or based on the potential improvements the user can choose to which maturity level it wants to belong (potential performance perspective) (Wendler, 2012).

With a wide range of application domains, maturity models have become a widespread tool for practitioners and academia to assist with coping with change (Röglinger et al., 2012). It is often said that the concept of maturity models found its origin in the field of quality management as early as the 1930s, referring to the work of Shewhart (Wendler, 2012). However, it took several more years for maturity models to be conceptualised as instruments for analysis and measurement. This was introduced by Crosby's five stage quality management process maturity grid (QMMG), published in the book "quality is free" (1979) and Nolan's stages of growth model for information technology, of which the final version was published in the same year (Wendler, 2012). These models concerned different subjects and fields, however, they contain similar key maturity model concepts that allowed for the analysis of the respective issues.

Weber et al. (2008) refer to the development of the Capability Maturity Model (CMM) for Software by Paulk et al. (1993), as the start of the modern use of maturity models. This model built on earlier literature, specifically referring to the QMMG and process maturity framework by Humphrey (1988). The resulting CMM has undergone several updates and achieved global acceptance for measuring maturity, reaching the level of a compliance standard (De Bruin et al., 2005). Due to its popularity, this CMM approach has been adapted in many other fields. Since then, more than a hundred maturity models have been developed that assess the maturity of capabilities of an organisation in a specific domain (De Bruin et al., 2005).

In the case of the CMM proposed by Paulk et al. (1993), the goal of developing a maturity model was for software developers to better understand their current situation and most critical needs, in order to select improvement strategies, however, it was not intended as a prescriptive model. In the case of software process maturity five levels were identified, namely, initial, repeatable, defined, managed and optimised, that lay successive foundations for continuous improvement (Humphrey, 1988). Each maturity level has been decomposed in several key process areas that in their turn are built up of five common features (Paulk et al., 1993). This starts by the commitment to perform the action, followed by the ability to perform describing the preconditions, the third feature is activities performed, fourth is measurement and analysis of the process and finally verifying the implementation (Ibid.). When these features reach the final step for each key area on that level, an organisation can then reach a higher maturity stage, also called a staged representation (Charles et al., 2011). On the other hand, continuous representations apply to an organisation's process improvement achievements referring to higher capability levels for that process (Ibid.).

Plattfaut et al. (2011) identified that such models are specifically important for dynamic environments where the need to adapt to the environments changes is high. Supported by earlier findings it is argued this is the case for the transportation sector where a paradigm shift is taking place. Based on a general examination of articles, de Bruin et al. (2005), identified three specific purposes for the application of maturity models, namely descriptive, prescriptive or comparative. A descriptive model assesses the as-is situation, clarifying organisations where they currently stand. A prescriptive model indicates how to attain a higher maturity level, by providing recommendations to get to the next level for each indicator. Finally, a comparative model allows for the comparison of the performance of different entities across organisations or industries. Depending on the goal of the maturity model, each of these uses can be included sequentially by adding additional information when developing the model.

However, there is also critique on these models, coming from both academics and practitioners. Plattfaut et al. (2011) questioned the need to always reach the final maturity level considering the cost effectiveness of these efforts. Röglinger et al. (2012) refer to criticism by several papers, mentioning the oversimplification of reality in these "step-by-step recipes". Additionally, these models are said to ignore the existence of equifinal maturation paths or internal and external factors that require the adaptation of standard models. Other concerns mentioned by Röglinger et al. (2012) are related to missing economic foundations, the focus on a predefined end state rather than factors influencing the change, lacking documentation or empirical foundation. In order to tackle these issues, a design science approach is increasingly taken in research, to guide the development of maturity models. Consequently, this approach demands documentation, sound research methods and a scientific basis (Röglinger et al., 2012).

Maturity models have been applied to many fields, however, Charles et al. (2014) found that in the transport field applications of maturity models have been limited. These models are developed at both academic institutions, and in private organisations to offer specific assessments or help in identifying specific products the user would need. For example, the IBM Intelligent Transport Maturity model allows cities to assess the maturity of their transportation system in becoming multimodal by deploying several technologies throughout their network. This was created to assist cities in developing their transportation strategies to compare their performance to the current best practices, focus on strengths and weaknesses of their transportation system and develop an ITS implementation roadmap (Houghton et al., 2009). Specifically, the maturity model allows cities to get an overview of the broad strategy components that leading cities combine in order to implement ITS successfully.

Other maturity models have been developed for infrastructure operators in the US, to assist them with improving their traffic management operating capabilities as they were regarded as more determining for the successfulness than the allocated budget (Gettman et al., 2017). The original tool has been widely used throughout the US supporting the relevancy of utilising maturity models in this field. Recently the original model has been updated to the new capabilities required for managing C-ITS services, indicating that these applications are fundamentally changing the functioning of transport organisations including within urban areas. The infrastructure operators are one part of transport organisations that can operate within an urban area, however, more organisations are involved as indicated before which could also be included in a maturity evaluation (Ibid.).

As such, the transportation field has become an area of continuous innovation pushed by new technological opportunities throughout transportation systems. For cities this has shown promising possibilities to take on crucial challenges, however, barriers delay necessary innovations. This is especially the case for C-ITS applications due to their novelty and inherent interconnectedness. Efforts have been done to share existing knowledge and best practices and a maturity model would allow city authorities to do this in a structured and comprehensive manner. Therefore, these findings indicate the promising nature of maturity models within the area of C-ITS deployment within cities. Establishing a maturity model based on the existing insights on implementing C-ITS in cities could help in providing a comprehensive view for city authorities and support the targeted wide scale deployment across Europe.

3 Literature review

This literature review is done according to the concept-based approach by Webster & Watson (2002) and recommendations by Van Wee and Banister (2016) in order to establish a high-quality review. To do this, firstly leading journals where the transportation field and IS field combine have been reviewed for relevant articles, however, due to the cross cutting relevance of this topic a broader approach needed to be taken. Therefore, this was followed by scanning online databases using specific keywords to find the most relevant research, but also support the replicability of the work. Scopus was used as a main source of literature, due to its broad coverage of journal publications and literature on hard sciences supplemented by findings from Google Scholar (Cledou et al., 2018). The search engines were employed to look for the key words of “Intelligent transport system”, “cooperative intelligent transportation system” and “smart mobility” combined with “urban mobility”, “maturity model” and “best practices”. The inclusion of smart mobility is motivated by the earlier observation that much of the literature concerning the implementation of these services has developed within this field. As a result, the searches on Scopus and Google Scholar led to 132 hits.

Additional criteria have been used in narrowing down the scope, namely, the time frame which has been limited to earliest 2010 as research in the ITS field has strongly developed since then (Van Wee & Banister, 2016). Similarly to the research by Munhoz et al. (2020) minimum criteria were set to filter influential papers. This meant that papers that have not been cited within two years after publication are being left out. After that, remaining duplicates were removed followed by a screening of the titles and abstracts for their relevance, significantly reducing the number of papers. This was followed by an assessment of the full articles resulting in the qualitative synthesis analysed for this literature review. As a third step in collecting relevant literature, a backward-forward method was executed as suggested by Webster & Watson (2002), where relevant earlier cited literature and more recent citing articles are included. The focus here was on papers from major transport and technology journals such as ITS international and Transport Policy, however, also conference papers were considered such as from the ITS world congress. As a result of this process, a total of 27 papers were identified for this literature review. These papers were then tagged based on key concepts which they covered, resulting in a concept matrix where for each paper the relevant concept is described, providing a structured compilation of this review in table 2.

Throughout these 27 papers, six common themes were identified shown in table 2. This concept-based approach will guide the literature review in a structured manner. Firstly, numerous papers have been concerned with defining what the general smart mobility field is concerned with, and how it is conceptualised. Subsequently, several comprehensive literature reviews have been executed in order to gather what technological developments have been happening within this field, identifying the role of C-ITS and the different elements this entails as well as challenges. Three papers identified the key drivers for smart mobility development, using expert input to assess which are the main enabling factors and how they are related. The role of city authorities as policy makers and existing strategies to support and develop smart mobility initiatives is also covered in literature. Another part of literature discussed the deployment of these initiatives and challenges and common practices related to that. Lastly, has attempted to measure, evaluate and benchmark smart mobility in cities, and the implementation capabilities of individual transport organisations.

Tabel 2. Literature list

Year	Authors	Definition	Drivers	Technologies	Policy	Deployment	Evaluation
2015	Albino et al.	x					
2017	Badii et al.					x	
2016	Benovolo et al.	x	x	x		x	
2020	Butler et al.			x	x		
2013	Caragliu et al.	x					
2011	Charles et al.					x	x
2021	Choosakun			x		x	
2018	Cledou et al.				x		
2017	Freitas et al.	x		x			
2020	Gallo & Marinelli				x		
2016	Garua et al.	x			x		x
2017	Getmann et al.					x	x
2007	Giffinger et al.	x					x
2015	Hamida et al.					x	
2009	Houghton et al.					x	x
2015	Kim et al.			x			
2017	Mangiaracina et al.			x			
2019	Miguel et al.			x			
2020	Munhoz et al.		x		x		
2014	Neirotti et al.	x	x				
2019	Orlowski & Romanowska	x		x			x
2020	Setyowati et al.	x			x		
2017	Tafidis & Bandeira			x	x		
2020	Vrscaj et al.				x		
2019	Warnecke et al.			x			x
2019	Yadav et al.			x			
2020	Zhang et al.					x	

3.1 Defining smart mobility

The term "smart" anything is surrounded by a vagueness that can lead to widely different interpretations of the subject at hand. It is considered to be a next step or upgrade of the related subject, related to an increased intelligence. In the case of smart mobility, researchers have established several definitions to identify the subject. Munhoz et al. (2020) argue that it has evolved from the convergence of the digital revolution and the transport industry. However, it is argued that Smart Mobility is still in its infancy and entails a broad vision, which makes that there is not one standard definition for it or what its describing attributes are (Faria et al., 2017; Neirotti et al., 2014). Additionally, what is deemed smart or intelligent is also strongly dependent on the specific situation of cities and their problematic (Munhoz et al., 2020). Therefore, it is important to understand how this is defined and where these interpretations come from as well as what this research is concerned with.

To define smart mobility, literature often refers to Giffinger et al. (2007) and their research on measuring smart cities in Europe. It is argued that Smart Mobility originated within this Smart City as of six main axes of a smart city, including smart economy, smart people, smart governance, smart environment and smart living. Within this interpretation, smart mobility is seen as using ICT and modern transport technologies for improving urban traffic and inhabitants' mobility. For the mobility aspect, Giffinger et al. (2007) emphasize the importance of local and international accessibility, the availability of information and communication technologies, and modern and sustainable transport systems. In their research on urban development Caragliu et al. (2011) follow this reasoning of putting ICT as the basis of smart mobility, but also includes other types of capital, considering "smartness" as increasing economic growth and a high quality of life, managing resources wisely and promoting participatory governance. Their interpretation is distinguished from the one by Giffinger et al. (2007), with their emphasis being more on social values, increasing the culture of learning and social inclusion as a strategy to enable sustainable smart cities.

Another approach focusses on the concept that developed at the Smart Cities program at the Massachusetts Institute of Technology (MIT) Media Lab (Orlowski & Romanowska, 2019). Mitchell (2007) uses the analogy of the city as a living organism, existing of several layers such as a structural skeleton and protective skin. The most recent development of Smart City, is characterised by the development of a nervous system through embedding new ICT's within the city. This enables the coordination of the different elements of the organism by sensing changes and responding to them in a coordinated manner. Subsequently, this approach puts the integration of ICT at the centre of smart city, nevertheless also arguing for the importance of the societal aspect within this technological evolution.

Consequently, the debate on smart city is moving between technology determinism, putting ICT at the centre to improve city productivity, and a broader view where the role of citizens and social capital is deemed equally important for fostering a cities' smartness. Within the broad interpretation put forward by the smart city measuring literature stream, Neirotti et al. (2014) distinguish two classifications that represent the importance of ICT systems as key enabler of the identified domain. In “Hard” domains, the approach to achieve optimisation by cities is through the investment in ICT and attaining a high use. On the other hand, “soft” domains refer to the bottom-up approach where citizens are being enabled to use data, and ICT itself plays a more limited role such as welfare, social inclusion and education. Based on their extensive literature review, the domain of transport, mobility and logistics which refer to smart mobility is classified as a “Hard” domain being ICT driven. Additionally, Neirotti et al. (2014) found that transport and mobility initiatives had one of the highest coverage of initiatives in cities, but also observing geographical differences, finding specific importance of these initiatives in Asian cities, where hard domains got more attention than soft ones. Moreover, Neirotti et al. (2014) subdivide the domain of smart mobility in city logistics, people mobility and info-mobility, referring to the distribution and use of selected dynamics and multimodal-information. Badii et al. (2017) for example, argue that the main challenge regarding smart mobility and smart city in general are related to data access, aggregation, reasoning and delivering services, emphasising the importance of this third aspect.

However, based on an extensive literature review, Benevolo et al. (2016) found that ICT is not necessary for smart mobility actions. They argue that smart mobility means a sustainable transport systems and all actions that help achieve this, therefore, it should also include initiatives that are not characterised by the use of ICT. Nevertheless, in the same research, they state that it becomes fundamental when the complexity, integration and extension of these programmes increases. They argue that even though ICT is not the goal but the tool, it has become necessary to achieve the final aims of improving citizens’ quality of live. In the bigger picture of smart city, Benevolo et al. (2016) see smart mobility as a slice crossing all components of smart city making it a crucial topic strongly affecting all citizens and stakeholders in the city.

Additionally, there is a reasonable amount of critique on the ICT centric approach to the smart city stream of urban development and therefore also on smart mobility. Warnecke et al. (2018) describe this critique as the existence of ICT elements does not necessarily imply that these technologies are used intelligently. Some authors specifically oppose the focus on technologies put forward by corporations such as IBM or Siemens AG, disregarding the cities’ complexity and values (Albino et al., 2015). Albino et al. (2015) found from literature that ICT initiatives are often the basis, but they have to consider the social and institutional context of the city. Consequently, it was noted that the concept of smart mobility has evolved from technology as a tool to improve transport planning to, the incorporation of the users as a key component.

Based on the previously cited research, literature generally sees smart mobility as a key factor in creating smart cities. It is argued that it is concerned with the coordination of goods, people, and information, based on information and communication technologies, which enables efficient mobility in the covered area (Choosakun et al., 2021; Faria et al., 2017). Even within the broader smart city debate where the ICT-centric and holistic approach collide, there is agreement that smart mobility is based on interconnected ICT. Munhoz et al. (2020) identified nine conceptualisations of smart mobility, and Faria et al. (2017) based their take on three definitions that share these attributes. The former research then filtered the essence of those conceptualisations in one generalised definition to be deployed as a comprehensive understanding of the approach:

> *"Smart Mobility is mobility that uses digital technologies to integrate systems and means of transport that interacts with users, aiming at a sustainable, safe, accessible environment that meets citizens' mobility needs."*

Similarly to Benevolo et al. (2016), this definition focusses on the goal of creating a more sustainable transportation system and a safer and more accessible city environment as a whole. Researchers argue that smart mobility should always be considered related to sustainability goals, however, depending on the research goal smart mobility can be interpreted broadly or centred around the concept of ITS development as is the case for this research. Ultimately, this shows that smart mobility is not one action but the result of many different technologies that get implemented and are integrated in order to create an intelligent system that achieves these goals.

3.2 C-ITS in Smart Mobility

The previous subchapter found that the urban development literature agrees on the centrality of digital technologies in Smart Mobility, however, these technologies are not static, but have been developing over time, redefining what is understood under Smart Mobility from a technical transportation field perspective. These technological developments can be found in individual papers that focus on the specific development of one application, but it is more difficult to find a holistic view of the possibilities (Benevolo et al., 2016). Consequently, research can be found that tries to describes the current technological innovations and best practices for smart mobility to fill this research gap. Cities are looking to these technological developments to relief the pressure on their transportation systems and transition from driving cities to smart transport and promote sustainability (Munhoz et al., 2020).

Benevolo et al. (2016) collected urban and technological smart mobility initiatives, with a focus on European cities, to set up a smart mobility taxonomy. The initiatives were classified with respect to the different key actors, being public transport companies and organizations; private companies and citizens; public bodies and local governments; and the combination of all of them. All initiatives include the aim to achieve a sustainable transport system by reaching at least one of the following goals: reducing mobility costs; reducing air pollution, reducing noise pollution; reducing traffic congestion; increasing safety; improving the speed of mobility. Subsequently, this allowed for the identification of the several technologies relevant to local city authorities. Related to public transport, they included the electrification of the public vehicles, efficiency norms and the automation of vehicles, followed by integrated management of public transport vehicles and integrated ticketing system. The domain of ICT applications for infrastructure is concerned with message signs about mobility, integrated traffic lights, parking guidance system and systems for speed control and management. Integrated policies to support smart mobility initiatives include traffic integration between public and private transport, integrated ticketing and the regulation of access to areas or redesign. As ultimate step in smart mobility, they refer to ITS applications that combine all actors. They are enabled by advanced information and communications technologies, which allow for integrated initiatives collecting, storing and processing data from activities related to mobility.

Based on the importance of an integrated approach to transport challenges, Mangiaracina et al. (2017) did a literature review on Intelligent Transport Systems as it is seen as the integrated application of ICT's to transport. This was done in order to connect the fragmented contributions in literature as well as to identify the role it plays for smart mobility looking at both people and freight transportation. While literature on freight transport was considering ITS in general, for people transport they identified three main application fields. The research existing of mainly case studies and simulation, which makes up a big part of the research in this field, touched on traffic management, public transport and parking management applications for people transport. Traffic management was limited to smart traffic lights, which sense incoming traffic and allow for the prioritisation of emergency vehicles. Public transport focussed on AVL, which provides management systems with its position, enables the provision of real-time information on its capacity and allows for the coordination with traffic lights to improve travel time. Lastly, parking management makes use of sensors and communication technology to help people find parking spots and check their availability. Mangiaracina et al. (2017) concluded that there is a lack of up-to-date and complete literature reviews on ITS in urban mobility and that papers mainly focus on the technical component, paying limited attention to value creation.

Reviewing the role of the Internet of Things (IoT) in the field of smart mobility, Faria et al. (2017) identify the same three drivers as Mangiaracina et al. (2017), namely, ITS, Smart Parking Systems, and Smart Traffic Lights Systems. ITS is regarded as the application of advanced technology to address transportation problems elaborating on Vehicular Ad-hoc Network (VANET). These networks form the basis of ITS applications, allowing for wireless vehicle-to-sensor, vehicle-to-vehicle, vehicle-to-Internet and vehicle-to-road communication, to consequently provide real-time traffic monitoring, traffic sign warnings, passenger recognition, accident detection, and speed and distance estimation. The observations by Faria et al. (2017) on Smart Parking Systems, and Smart Traffic Lights Systems are similar to the findings before, identifying that many solutions, techniques, models and applications exist to solve challenges in the smart mobility field. They argue that although there are challenges with implementing technologies such as C-ITS services, investments in these aspects would bring broad benefits to transportation systems and the people in general.

Tafidis and Bandeira (2017) gathered best practices of European cities using ICT in order to create more sustainable urban transport. They identify three channels to do this through, based on ten practices, either through a shift to public transport, through a more sustainable use of existing infrastructures, or through a modal shift to soft modes. The first action has been supported in several cities by the provision of multimodal journey planners, offering smart ticketing systems and the collection of real-time passenger information using Automatic Vehicle Location Systems (AVLs) as already mentioned by Mangiaracina et al. (2017). In order to support the move to soft modes of transport, ICT has been used to enable bicycle sharing schemes in cities in almost every region of the world, promoting the environmentally friendly method of transportation. To make more efficient use of existing infrastructure Tafidis and Bandeira (2017) found traffic signal control and smart parking as mentioned by the research before, but also identified additional practices. Electronic Fee Collection (EFC) has been used in urban toll schemes to decongest downtown areas to influence traffic demand and green transportation. A newer approach in traffic management also includes pollution monitors to optimize the traffic flow also considering its ecological impact. Lastly, they argue that C-ITS is the main direction for the future of ITS, allowing for the direct interaction between vehicles, road infrastructure and transport authorities, allowing them to share data and information and act on it. Novel applications such as emergency braking, optimal speed advice GLOSA will improve the efficiency of existing ITS, paving the way for automated vehicles.

Looking to the future in a search to define smart mobility of 2025, Kim et al., (2015) support this key role for ITS and the possibilities of C-ITS in the development of smart mobility. Together with sustainable and smart vehicles, and innovations in big data based vehicular networks and cloud server innovations, they form the smart mobility of the future. They refer to Burns (2013) when stating that the building blocks of future vehicular technology will among others be connected and coordinated. Subsequently, the connected vehicle concept or C-ITS will enable the delivery of the most efficient, safe and secure mobility in the V2X environment according to Kim et al., (2015). Innovations in cloud technology and mobility applications are improving the accessibility of traffic information and management, while at the same time they expect big-data processing technology to be combined within the vehicular network, increasing processing and computation power. These applications create a cooperative system which should eventually support fully-automated driving. It does this by delivering a wealth of information and services to the user, such as safe driving, emergency rescue, advanced traffic management information.

More recently, Butler et al. (2020) provide an overarching technology review of the most commonly discussed urban mobility innovations in the smart mobility literature. The final categories determined from this review were:

(a) Intelligent Transport Systems, (b) Driving Automation Systems, (c) Alternative Fuel Systems; (d) Shared Mobility Services; (e) Demand Responsive Transport; and (f) Integrated Mobility Systems.

They confirm the central role ITS has commonly become to play in urban transportation systems looking to take a holistic approach. Its applications within public transport, private travel and shared mobility led Butler et al. (2020) to list and summarise seven application areas and driving technologies. They go beyond cloud computing mentioned by Kim et al., (2015), and refer to the importance of 5G networks for faster wireless transmission of data; IoT to help facilitate the collection, transmission and analysis of data; AI, to allow for automated decision making and learning making systems more dynamic; and blockchain, as a decentralised store of information facilitating crowdsourcing of technology if needed. Çaldağ and Gökalp, (2020) specifically put forward the enhancements in transparency, immutability, traceability, and efficiency blockchain could mean for ITS, however, it is still in the infancy stage. As has been said before, Butler et al. (2020) mention the relation between AV and C-ITS as well as opportunities of new fuel systems. Lastly, developments in ITS, ICT, GPS and the use of smart phones have led to the development of integrated mobility systems providing multimodal transportation options, as well as innovated the offer of demand responsive transport.

3.3 Drivers of smart mobility

Based on the discussed literature, it has been found that smart mobility is frequently defined as underlying ITS and C-ITS technologies. However, using a similar technique Yadav et al. (2019) and Miguel et al. (2019) researched which technologies are the drivers of smart city in order to assist policy makers and practitioners in better understanding smart mobility. This research was motivated by weaknesses in measures of smart city, which use indicators that measure sustainability rather than how "smart" a city truly is (Miguel et al., 2019). To do this, Yadav et al. (2019) and Miguel et al. (2019) applied clustering and impact classification techniques on identified variables and assessed their relations using the Fuzzy technique. Consequently, they identified connections between different elements in research by consulting expert views to rank the importance of the identified elements and their cause-and-effect relationships, ensuring a better conceptualisation of smart cities. Based on expert consultations and the subsequent use of a clustering method in Portugal, Miguel et al. (2019) identified six main clusters of smart city characteristics including people, planning and environments, technology, infrastructure and materials and transportation and mobility. This last group of transportation and mobility had been identified as one of the most important elements in developing smart cities, with the integration of public transportation criterion identified within this group to be the most impactful for developing smart mobility.

Yadav et al. (2019) undertook similar research for developing contexts, focussing their research on the Indian context. They started with a literature review, followed by the clustering of key smart city enablers, also finding six distinct groups. Among these dimensions, they found that strategy and policy oriented were the most important enablers for smart city, with mobility again playing an important role. The main accelerator for the mobility domain was the development of ITS which benefits from an accelerating pace of public transportation and intelligent parking systems. The authors argue that differences can be explained by the context specificity of smartness as well as the employed methods (Miguel et al., 2019). Nevertheless, these findings confirm the importance of public transportation innovations and its integration with other modalities, creating a multimodal system, and ITS for integrating existing transport technologies, combined forming smart mobility. The identification of these drivers by the previous two papers support the focus of earlier research on those specific technological developments.

After researching the drivers for increasing the intelligence of cities in 2018, Munhoz et al. (2020) did the same for the intelligence of urban mobility in Brazil specifically. They executed an extensive literature review finding 26 drivers followed by a survey with 181 professionals in the field to identify the which of them are priorities. Based on the drivers' relationship, three groups were distinguished, namely governance, technical solutions and technological resources. All drivers were considered important, however, experts considered seven drivers a priority, of which five were related to governance and two to technical solutions. For governance these drivers were public policies, environmentally friendly policies, urban mobility plans, maintenance and safety. For technical solutions the priorities were on accessibility, and walkability. These results show the importance of city authorities and their public policies for increasing the intelligence of urban mobility as found by Yadav et al. (2019).

Similarly to the previous research, Munhoz et al. (2020) refer to the importance of context specificity arguing that the Brazilian reality is similar to what other underdeveloped and developing countries are facing. These countries need to work within tighter budget constraints, with Munhoz et al. (2020) for example suggesting the use of bottom up approaches for increasing the intelligence of urban mobility, which are less capital intensive such as using mobile phone applications rather than installing widespread infrastructure. Consequently, they believe that developed countries with a more consolidated infrastructure would show a technological bias which they didn't find in Brazil.

3.4 The deployment of ITS

The deployment of smart mobility and C-ITS in cities is a continuous process that can be characterised by several elements. Regarding the implementation of smart mobility actions and programs, Benevolo et al. (2016) identified three phases of maturity which they called: Starting, Intermediate and Mature. In the starting phase, actions are mainly working on the less ICT intensive technologies in pilot phases. Benevolo et al. (2016) describe these actions as often immature, not spatially coordinated, difficult to replicate and limited to a small portion of the urban area. The subsequent intermediate phase is characterised by smart mobility governance actions such as pilot projects repetitions, integrated mobility plans and measuring of the different impacts. Finally, in the mature phase, ITS is used to collect, process and share data, information and knowledge in a complex and integrated mobility system. These steps form the evolution of smart mobility implementation and are successful when an extensive set of ITS technologies is implemented, based on a large knowledge about smart mobility in the city and good citizen involvement and awareness about the opportunities of the existing system, with Benevolo et al. (2016) emphasising the importance of responsible behaviour of citizens. Subsequently, the implementation of smart mobility is argued to be a continuous process of developing several technologies to establish an integrated system.

However, research has found that the creation of new policies to support smart mobility have not always been sufficient to guarantee a succesful initiative implementation. Vrščaj et al. (2020) studied the case of the Netherlands where a roadmap was put in place to improve the results of smart mobility initiatives and ensure user involvement. They found that the roadmap failed in the user involvement aspect, due to the transfer of responsibilities and the lack of one specific accountable organisation. The different partners largely went back to the techno centric approach dominant in the mobility field. Rather than taking into account the needs of users, the organisations focused on optimising customer mobility behaviour. To improve this, Vrščaj et al. (2020) argue for an inclusive approach, involving actors with different perspective, and a responsible central organisation pushing for user involvement and taking more modern appraoches. These findings correspond to earlier literature focussing on the need of user involvement to ultimately attain the acceptance of the developed services.

Considering the innovations in ITS leading to C-ITS, Choosakun et al. (2021) discussed common success factors in the ITS development in order to support the development of C-ITS in Thailand. They identified a list of five factors that affect the deployment of ITS applications, by looking at common practices in more advanced areas. Firstly, Choosakun et al. (2021) found that to ensure the successful implementation of ITS practices, a policy plan on Smart Mobility development should be present, including both medium and long term plans and considering the different levels of government. Secondly, C-ITS pilot projects enable the more large scale deployment of an ITS as found in the paragraph before. Thirdly, standards and framework agreements between the involved public, private and research institutes allow for the efficient cooperation for initiating C-ITS projects. The deployment of national documentation on standards and architectures of C-ITS has been taking place in many important regions in the world, leading deployment and ensuring crucial interoperability. A crucial point on stakeholder cooperation and regulation needs to be considered, with leading practices being having one leading ITS development agency, a C-ITS working group with the different actors involved, and public-private cooperation. Lastly, R&D benefits strongly from a research taskforce working on development.

As a result, Choosakun et al. (2021) formulated several strategies and actions that can be taken to improve the success of the implementation of these smart mobility solutions, with clear goals of the system development to motivate the private sector. In accordance with Vrščaj et al. (2020), they argue for assigning a responsible agency for the development plan and stimulate stakeholder cooperation in a working group, and by designing an architecture for a standard and framework. The utilisation of lessons learned should also be promoted as stated in research before, an important component there was the need to create the necessary capabilities within pulbic organisations. Also, a monitoring and evalution system utilising key performance indicators (kpis) play an important role. Lastly, concerns surrounding the sharing of data need to be resolved, namely, security issues and data exchange and sharing agreements with the different partners.

Badii et al. (2017) argued that the main technical issues regarding smart solutions are related to data access, aggregation, reasoning, access and delivering services via Smart City APIs. These services usually integrate open and private data, and static and real time data coming from the administrations and private operators. Subsequently, they propose an architecture to ensure the effective use of data, and enable the creation of sophisticated smart mobility services. Concerning the security of ITS, Ben Hamida et al. (2015) note that despite the great potential, there are many challenges and issues that need to be tackled first in order to create safe applications. While the applications are made to improve the safety and efficieny of traffic, its reliance on wireless communications exposes it to several threats. This challenge has become increasingly important, as it has been observed that security challenges form a social barrier to the adoption of ITS systems. They analysed an ITS safety application considering the existing European ITS security standards, finding that urban environments are challenging for existing standards, whithout impacting latency which is crucial for these type of applications. These challenges have to be considered in the development of new applications, and require close attention.

3.5 Policies for ITS implementation

Previously covered papers mentioned the importance of city authorities in developing smart mobility solutions. When administrative authorities show interest in promoting sustainable mobility, their governance actions can drive change (Garau et al., 2016). Munhoz et al. (2020) identified the importance of these policy drivers above other enablers of smart mobility.

Butler et al. (2020) argue that the fast evolving technological changes require a constant refinement of policies. Subsequently, they propose nine policy recommendations relevant to the implementation of smart urban mobility. While some of them go beyond intelligent transport systems, it is relevant to be aware of the broader options for policy makers. Firstly, as smart mobility is increasingly reliant on ICT and smart devices, decision makers need to invest in communication networks to ensure high speed and adequate coverage, as well as security standards and safety. Secondly, decision makers should consider investing in smart infrastructure, not only to benefit from ITS for managing traffic flow and providing information, but also for future innovations that will harness the benefits of these systems. Promote shared mobility schemes, electrical vehicles as well as autonomous vehicles to encourage more sustainable transport modes, as well as considering the accessibility of employment locations. Payment and access options should be simplified for users by exploring integrated mobility services that are easy to use and accessible by all service providers. Lastly, effective traveller information and incentives should be deployed to influence travels' decisions.

In order to guide policies and enable a coherent implementation of ITS, Setyowati et al. (2020) propose the usage of a strategic plan for the city of Surakarta. They argue that a middle to long term strategic plan is highly important for city administrators in providing guidelines for the policy development and eventual implementation. They used a SWOT analysis to incorporate all factors and as a result provided four context specific strategies for city officials. The first strategy is to develop and enhance cooperation with stakeholders in creating smart mobility plans refering to the previouslt discussed work by Vrščaj et al. (2020). Stakeholder engagement is crucial in developing a smart mobility roadmap in order to include all persperctives and needs. Secondly, e-government applications need to be improved and intensified. Thirdly, a strategy on strengthening the integration of intermodal modes of transportation in Surakarta is important to improve mobility. Lastly, they propose the development of a strategy synchronising policies of central and regional governemnts to dissuade people from using private vehicles. While these strategies are context specific, generic elements can seen to be relevant for most, if not all contexts such as the stakeholder involvement and the need for policy allignments between different authorities.

Considering these policies, authors have been arguing that cities should not try to reinvent the wheel but learn from others. Subsequently, Tafidis and Bandeira, (2017) identified the need for policy makers to take advantage of these best practices related to the increasing availability of sensors and generated data by transportation systems. Within the mobility sector they find there is a lack of well-structured policy guidelines to leverage ICT, sensing systems and big data. Policy makers face challenges in learning what exists in the field, and subsequently, how to implement regional policies effectively. As part of the Cooperative information platform for low carbon and sustainable mobility (CISMOB) project, they aim to overcome these challenges and promote the sustainability of urban transport infrastructure through ITS. To achieve this policy change, the importance of knowledge exchange on different levels is emphasised. Organisational and individual level knowledge is fostered by the collection and exchange of best practices between cities. Additionally, an exchange between local authority staff and academic institutions disseminates experience and skills relevant for the creation and implementation of urban mobility ICT. Finally, in order to efficiently improve mobility, they argue that local mobility programs should be mobilised in a holistic approach, rather than minimising a particular parameter.

Similarly, in the paper called *"A taxonomy for planning and designing smart mobility services",* Cledou et al. (2018) address the issue of developing specialised and contextualised smart mobility policies. They agree that the learning from existing, and importantly also failed mobility policies, between governments is a great source of information to adopt to their local context. However, for this exchange to be effective best practices need to be better and more consistently described, resulting in the development of a taxonomy comprising eight dimensions: type of services, level of maturity, type of users, applied technologies, delivery channels, benefits beneficiaries, and common functionality. This will help policy makers in defining smart mobility strategies, by helping in the identification of the relevant stakeholders and developing a business case based on the presented benefits. Another lesson learnt was that the formulated strategy should strongly rely on citizen engagement, from the initial communication to user feedback after implementation. Finally, besides the policies for implementing smart mobility, regulatory obstacles should also be considered if new services are to be promoted. As such, the literature on ITS policy is finding similar elements that need to be considered in these type of projects, focussing on the challenges of available knowledge on these innovations as well as the benefits of exchanging knowledge between cities to help them focus on their strengths and weaknesses.

3.6 Evaluation

With the evolution of these innovations, researchers have been making an effort to evaluate and track the implementation of smart mobility in cities. As part of the urban development literature, Giffinger et al. (2007b) developed a smart city indicator, ranking cities based on six dimensions, which includes smart mobility as one of its six dimensions. The goal of this was to develop a ranking that includes the challenges European medium – sized cities face and that identifies their main strengths and weaknesses, allowing them to position themselves compared to other cities. This is argued to be important within the globalisation and trade liberalisation taking place, making cities compete against each other. Within this approach, smart mobility is defined as transport and ICT, and measured with nine indicators representing local accessibility, (inter-) national accessibility, availability of ICT-infrastructure and, Sustainable, innovative and safe transport systems. As a result, they created a ranking of seventy cities in Europe, which they noted was particularly found to be useful for cities in their marketing and planning section to position themselves within the European Urban system.

While the smart city indicator by Giffinger et al. (2007) was developed within the urban development field as a score to position cities within the international competition, other evaluation attempts have been taking place within the transportation field. Garau et al. (2016) found for Cagliari, that the Urban Mobility Plan (UMP) outlines the objectives of the city, including possible (technological) intervention scenarios, which is seen as a powerful tool to transform the city and develop a more sustainable transportation system. Therefore, they proposed an evaluation methodology for smart urban mobility that allows city authorities to monitor their actions and asses the effectiveness for reaching their proposed goals. To do this, they developed a synthetic smart mobility indicator combining the main modes of transport with technologies that manage movement. Within this methodology, they take account of the characters of the individual city regarding the population and size of the area. The authors argued that this methodology allows for the comparison with other cities, helping practitioners to orient their mobility to international best practices and include this in their UMP to improve their transportation systems. As such, it addresses the policy gap discussed in research before.

While these indicators provide a general score, it is difficult to represent the diversity of the field as well as give suggestions on how to improve these dimensions. Moreover, Warnecke et al. (2018) found that evaluation tools are missing that allows cities to benchmark themselves and identify their maturity based on scientific research. Therefore, they developed a maturity model for practitioners to evaluate their smart city initiatives, track progress and determine their competitive position. Besides benchmarking the competitive position of cities, their goal is to provide local authorities with guidance on how to improve their standing similarly to Garau et al. (2016). However, Warnecke et al. (2018) argued maturity models to be the best tool, over rankings, for identifying strengths and weaknesses, and defining measures for improvement. They situated the development of these kind of tools within the “new public management” (NPM) paradigm, where private sector management tools started to get applied to public administrations as well.

The tool itself was developed according to the process by de Bruin et al. (2005), and for the first version focused on smart mobility, due to its importance in developing smart and sustainable cities. The definitions and maturity levels were based on the five CMMI levels, starting from no smart mobility system in place to continuous smart mobility planning. Average thresholds were assigned to each level, outlining an evolutionary path to the most mature smart city. Through a systematic literature review focused on Europe Warnecke et al. (2018) identified 47 indicators which were reduced to 36 after expert interviews. These indicators were grouped into six themes, namely, policy and planning, ICT integration, intermodal integration, public transport performance, environmental impact and social impact.

The resulting Smart City Maturity Assessment and Benchmarking (SCMAB) tool was made available as an online assessment in order to make the assessment easily accessible and affordable taking into account the practical needs of practitioners. Additionally, this would promote a higher participation, allowing for better benchmarking, and giving cities the opportunity to compare themselves with similar cities to get more representative insights in best practices. Subsequently, they provide practitioners with strategic guidance on smart mobility policy, and enable a knowledge transfer between academia and practitioners, but also between cities. Within the benchmarking function, the optionality for individualisation options was considered, as some indicators might be irrelevant to a city's development, however, the possibility to compare with similar cities allowed for the inclusion of these differences. These efforts were within the smart city development literature, evaluating the outcome of smart mobility development within a city.

The application of maturity models has been taking place in the field of smart city, however, Charles et al. (2011) found that the utilisation of these tools is limited in the transportation field. Specifically, they were looking to apply such an approach to the capability of traffic management systems, in order to help organisations benefit from the ongoing improvements in these technologies. As such, they employed insights from earlier maturity model developments in their own research, starting with the IBM Intelligent Transport Maturity Model for cities. They developed a maturity model on transport ICT integration, covering the use of ITS to move from single mode operation to multimodal transport services (Houghton et al., 2009). The authors of the model argued that the transportation field has seen the highest adoption of technological solutions within many smart cities. However, during their research, they found that implementing ITS is about more than a smart software solution, it requires cities to implement a broader strategy integrating several technologies. In order to develop an efficient and comprehensive strategy, including international best practices, a maturity model is ideal. While the maturity model has been the result of extensive research around the world by IBM on a number of cities for several years, there is no documentation available on the exact process followed or methods used, however, they mention detailed discussions with city officials later in the report as an important source of information.

Subsequently, five maturity steps were defined reflecting how integrated the transport modes and technologies of a city are. Each of these five steps is built on three main strategy areas, namely, governance, transport network optimization and integrated transport services. Each of these levels exist of between three to five specific indicators that can be more decisively assessed. Governance relates to the strategic plans in place, the performance management and demand management by the authorities. Transport network optimization relates to sensing of incidents and the collecting, analysing and operationalising of data. Thirdly, Integrated transport services focus on the customer interaction aspects such as customer relationships, payment systems and the traveller information provided. The individual steps of these indicators follow the typical progress each city goes through when developing a multimodal optimized transport system. Consequently, it particularly differs from the SCMAB described before, by focussing on technologies, and not including the last two dimensions which on the sustainability goals.

The IBM Intelligent Transport Maturity Model can be applied by city officials to assess their progress compared to the global leading practices or compare it to typical practices represented in the maturity model. When the city has then measured its progress, it can validate its strategy compared to global practices and further develop an ITS implementation roadmap. Five general recommendations are given in the subsequent part of the report on common issues in strategy development reflecting earlier points covered in this literature review. Cities should develop a flexible and long term ITS strategy, adopt customer-centred approaches, integrate service delivery, secure funding and apply new business models and effectively manage implementation. Especially related to this last point, Houghton et al. (2009) noted concerns from cities about having the capabilities to implement these projects. The success of these projects depend on several factors such as clear governance structures, effective change management, project teams and the measurement of progress, however, they were not covered in the model.

Since the release of this model many developments have taken place in the ITS field discussed before, which have not been taken into account. As described before by Tafidis and Bandeira (2017), C-ITS is the future of ITS, and these technologies can be seen to go beyond and are not necessarily meant for developing multimodal transport system, but can also be used to make more efficient use of existing infrastructure. Additionally, commentary from research has come on the corporate approach to smart mobility implementations as well as the customer focus over user involvement (Albino et al., 2015; Vrščaj et al., 2020).

Therefore, the CV CMM was developed which targets infrastructure owner-operators responsible for developing the V2I infrastructure and applications, and also city authorities responsible for transportation programs (Gettman et al., 2017). They motivated this decision based on research finding that budgets were not enough to determine who worked best, but the available capabilities were instrumental for this. Before that, the Transportation Systems Management and Operations Capability Maturity Model or TSMO CMM was developed to evaluate how effective transport agencies are in effectively managing and implementing integrated transport technologies. But, as ITS kept advancing with new technologies resulting in C-ITS, a maturity framework had then been developed for the USDOT, emphasising improvements on existing ITS capabilities that need to be made and new ones that need to be developed for deploying C-ITS services.

This model distinguishes itself from earlier research, as it measures how well the subject is prepared for implementing C-ITS, rather than evaluating the number of technological components or state of C-ITS. Therefore, the first three dimensions of the model are process-oriented, focussing on the technological core process of the system under investigation, namely, business processes including planning programming and budgeting, systems and technology and performance management. The other dimensions are institutional focussed related to the organisational background of the capabilities, namely culture, organisation and staffing, and collaboration. This approach ensures the covering of the subject in a holistic manner. After the assessment, the document written by Gettman et al. (2017) suggests a process for agencies to identify the priority dimensions and review the actions they have developed for each step in order to create an action plan to improve their capabilities. As the end goal, agencies are expected to have a strategy mainstreamed, with standards in place for deployment and formalised the use of data and analytics for V2I applications. This maturity model provides a comprehensive tool to assess individual IOOs on their capabilities for implementing CV or C-ITS and puts forward important dimensions, however, it does not include the earlier challenges defined in literature for city deployment as a whole.

Based on this, Charles et al. (2011) found that maturity models could be a practical tool in this field, in their case applying these insights to traffic management. Specifically, they identified several aspects that make their maturity model useful for these agencies, namely, it allows for the cross-comparison with other jurisdictions helping transferring understanding, allows for the identification of weaknesses by collecting the different aspects to traffic management in one construct, supports process improvements by providing clear steps and it provides clear information for decision makers to consider who and what requires support. An important benefit from this model according to Charles et al. (2011) was that it can be adapted from a unit-level self-assessment to a multi-stakeholder assessment including multiple jurisdictions allowing for a broader assessment such as in the IBM maturity model. Moreover, individual maturity models could be developed for specific traffic management tasks as was done in the TSMO CMM, developing practical advice for each of these elements. Moreover, the evolution of the TSMO CMM to the CV CMM indicates the need for assistance in the deployment of novel C-ITS services.

4 Methodology

As the previous chapter stated, based on previous research, cities could benefit from a tool to evaluate their maturity in C-ITS services implementation. Therefore, the remainder of this paper will focus on the development of such a tool in the form of a maturity model. Consequently, this chapter describes the employed methodology that enables the development of this artifact in a scientifically backed manner. Therefore, the most influential and comprehensive works on designing maturity models will be operationalised below, employing a design science approach for the model development and in that way contributing to the IS field. This will provide the framework for the next steps, and allow this research to benefit from the practical knowledge and experience acquired during previous maturity model developments. This means the basis for the design of the maturity model will lay in proven methods that have been used before, and are established within the field.

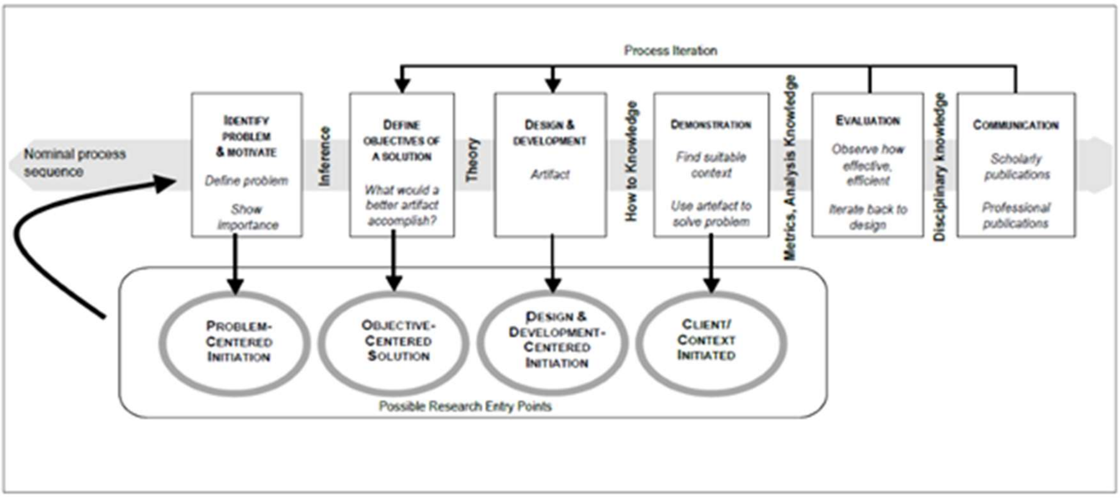
4.1 Design Science

Exploring the composition of the terminology, design science is focused on the designing activity, commonly associated with architecture, urban planning or engineering, however, this can also be applied in other fields to serve a scientific purpose (March & Smith, 1995). The Design Science paradigm concerns the extension of, “the boundaries of human and organizational capabilities by creating new and innovative artifacts” (Hevner et al., 2004). Consequently, March and Smith (1995) argued for the adaptation and application of this paradigm to the field of technology, in order to go beyond the practice of theory application and knowledge-production, and support the development and implementation of artifacts. As the IS field is an applied research discipline, the application of theories from other disciplines is common, providing a theoretical basis that can be adapted to practices in this newer field (Peffers et al., 2007). As such, the design science paradigm is applied for creating the maturity model artifact, and can help create real world applications while generating additional knowledge to the academic field (Hevner et al., 2004).

The application of design science in information systems research is not uncommon, and has seen a rise in popularity as a significant amount of research is concerned with the development of innovative artifacts (Peffers et al., 2007). A highly influential paper by Hevner et al. (2004) provides seven guidelines for well carried out design research in the field of IS in order to align design-science research with real-world applications. Under artifacts they understand: constructs, methods, instantiation and models, emphasising its relevance for the development of maturity models. However, Peffers et al. (2007) argue that for IS research to maintain its relevance, an accepted common framework is necessary for Design Science research in the IS field. Here, they follow the argument that as the outcomes of design science are expected to differ from other research, some guidance on the unique process to do so should be provided. Based on the guidelines by Hevner et al. (2004) and other relevant literature, Peffers et al. (2007) built a Design Science Research Methodology (DSRM), including principles, practices and procedures. These guidelines have been employed numerously in research and also form the structure for this research.

The DSRM procedure includes six steps that have been identified by literature as crucial for designing artifacts. These steps are recommended as a mental model that DS research in the IS field should follow, therefore, in order to ensure the scientific value of this research, this approach is taken. The DSRM procedure steps are the *problem identification and motivation* step, where the problem is demonstrated and its relevance identified. Secondly, the *objectives of the solution* are to be defined which can either be quantitative (in what way will the new solution be better) or qualitative (description of how a new artifact is supposed to support solutions). The core of the research is then the *design and development* phase where the artifact is created, which includes deciding on the artifact functionalities, architecture and then creation. After that the artifact needs to be *demonstrated* in order to prove how it would solve some instance of the problem through some kind of an activity, followed by a more formal *evaluation* comparing the objectives of the model with the actual results. Finally, the results need to be *communicated*, including all documentation to provide the right framing and scientific basis.

Figure 1. DSRM procedure



Source: Peffers et al. (2007)

The nominal process identified by Peffers et al. (2007) visualised in figure 1 from the paper covers an extensive approach to the development of an artifact which allows for multiple entry points, depending on the initiation of the development. Peffers et al. (2007) argued that based on the approach to the model design, the sequence of these steps can be slightly different. Either, a problem-centred approach, starting with activity one, or objective-centred approach, starting with activity two is taken in research. We can see that part of this procedure is already undertaken in the previous chapters of this paper, started by identifying the problem in the research background, and the defined objectives of the solution in the literature review. Such a problem-centred design science approach follows the original sequential order of the DSRM and will subsequently undertake the design and development step of the artifact. However, research does not have to cover all steps described within one paper, based on the goal of the research, certain steps can be omitted or left for future research.

The first two steps of the design science methodology have already been covered in the research background and literature review chapter of this research. The research background chapter gives answers to the questions posed in the first scoping phase by de Bruin et al. (2005), namely*, what is the target domain, who is the target group, what is the problem, and why is it relevant or what is the actual demand*? After that, the literature review covered the existing research and maturity models in this field leading to specific questions and objectives that will lead the further development of the model (Becker et al., 2009). This follows the recommendations suggested by Peffers et al. (2007) for this step, namely, having the knowledge of the state of problems and current solutions. Based on these steps, the *model design* and *evaluation* step cover the main body of the remainder of this paper.

Additionally, the *communication* phase is limited to the writing of this paper. The goal of the communication or deployment phase is to communicate not only the maturity model, but the whole development idea, from the importance of the problem to the effectiveness and rigor of the design (Peffers et al., 2007). This paper plays the role of the documentation and communication tool, developed within the style of the IS field, providing both a management and technology focus. Crucial is to convey the message to the relevant stakeholders that could benefit from these insights in order to ensure that the model is taken advantage off (Hevner et al., 2004). The audience for the conceptual model at the moment is academics that would want to further develop this field or practitioners that want to benefit from the operationalisation of the insights.

Peffers et al. (2007) suggest general methodological guidelines for the application of design science research, however, as suggested in the paper, procedures can be adapted to the specific field or artifact. As the development of a maturity model has been identified as the goal of this research, it was decided to look into adaptations of the next steps in this field. Subsequently, two major papers that apply the DS approach for designing maturity models were identified, and have been reviewed in order to derive specific steps and guidelines for the designing and review steps of the maturity model. Together with the general design science approach, these insights form the basis of the methodology, and guide the development of the maturity model hereafter.

4.2 Procedural models for Maturity Models

While researching maturity models development, two papers stood out that established procedural models for maturity models in the IS field using a design science approach. Firstly, de Bruin et al. (2005), developed a generic framework to guide the creation of maturity models across a range of domains. The goal of their research was to address the gap of a lack of a general development framework that is, “theoretically sound, rigorously tested and widely accepted“ (De Bruin et al., 2005). They based their framework on their experience in developing the Business Process Management Maturity (BPMM) and Knowledge Management Capability Assessment (KMCA) models, grounding it in a practical basis. Six phases are identified as part of the framework suggested by de Bruin et al. (2005), to develop a descriptive maturity model which can than evolve to a prescriptive and comparative model. They provide detailed descriptions of these phases in their paper, providing valuable information on methods and approaches that can be taken to tackle each step.

Secondly, Becker et al. (2009) created a procedural model based on the eight design science requirements by Hevner et al. (2004), taking into account the critique by Zelewski (2007), and informed by existing well-documented maturity model development examples. The research originated from the strong growth in IT management maturity models, demanding a general approach that ensures the quality of newly designed models. This resulted in a generally-applicable eight phase model emphasising the importance of an iterative approach to these processes, returning to earlier steps after evaluation phases. Consequently, the visualisation by the authors takes the form of a flow chart, which had been described with possible procedures for each step, inspired by the reviewed examples. These steps are distinguished in more practical steps, providing clear guidelines for developing a maturity model in a structured way.

After exploring both empirically supported and design science based procedural models, valuable guidelines for the development and evaluation of the maturity model have been identified. While the general flow and bottom line of the procedural models are similar, different steps can be found. Motivated by the DS requirements by Hevner et al. (2004), Becker et al. (2009) identify more subdivisions and provided documentation guidance for each step, while de Bruin et al. (2005), conceptualised each step broader. Nevertheless, their conceptualisation also provides specific practical guidance and considerations that are valuable for this research. Consequently, the insights of both procedural models will be combined with the DSRM template for design research, in order to ensure the best fit for this case.

Consistent with the needs of this research, the main focus lays on the central components of the design science approach, namely the design and development of the model, and assessing the outcome. As such, not all steps are covered due to the broadness of the process and the time and means limitations of this research. As has been said, the goal of this research is to develop a comprehensive maturity model, building on the recent and innovative literature in this field to bring together the different aspects identified in literature. Therefore, the focus will lay mainly on the compilation of the different innovative aspects in a holistic manner rather than the provision of a ready-to-use tool. Consequently, the exact steps this research follows are described in the subsequent subchapter, utilising the concepts of the maturity model specific procedural models. This methodology is in line with the general steps of the design science methodology and procedural models by Becker et al. (2009) and de Bruin et al. (2005). In line with the design science approach taken in these models, the steps will be explicitly documented in order to ensure the scientific grounding of the model development and have been determined in respect to the goal that has been put forward at the beginning as well as the limitations of time and means of this research.

4.3 Model Design

For the model design step, the suggested methods by de Bruin et al. (2005) and Becker et al. (2009) are followed. This step is the focal point in the development of the eventual maturity model and overlaps with the design and populate steps from the de Bruin et al. (2005) procedural model. Becker et al. (2009) recommend an iterative approach to the designing of the model, starting from the highest level structure and moving downwards to the levels and attributes similarly to what de Bruin et al. (2005) found. The appropriate methods need to be defined for each level of abstraction in order the develop a suitable model within the outset procedure. Each of these steps is described subsequently and guide the model development of this research.

The design phase commences by identifying the model structure and underlying mechanisms that determine the basis of the maturity model. To do this, it is suggested by Becker et al. (2009) to consider existing models in order to utilize earlier insights and concepts as well as relevant methods. Based on the earlier examination of these models that led to the problem definition, researchers should decide to employ one of several strategies, either deciding to design a completely new model, enhancing an existing one, combining several or transferring structures and/or contents. Therefore, the first design step entails identifying the structure or model architecture. Earlier discussed insights in the previous steps of this research already discussed relevant models and suggested the utilisation of information from existing models and supplement this with novel insights from the latest research on C-ITS implementation.

Secondly, to further develop the model, de Bruin et al. (2005) suggest either a top-down or bottom-up approach for defining the maturity levels. In relatively new fields, the maturity level and concept definitions are written first and measures are tailored to that. The second bottom-up approach is where measures and requirements are defined first and the definitions then have to reflect that (De Bruin et al., 2005). Due to the novelty of C-ITS services identified in literature, with little evidence of what maturity is for C-ITS implementation in cities, a top down approach is taken for developing the maturity levels. This means that the designing step will first describe what represents maturity, before is looked at how this can be measured by the maturity model (De Bruin et al., 2005).

To do that, firstly the dimensions of the model need to be defined, identifying what needs to be measured in the model. These dimensions should be mutually exclusive and collectively exhaustive, providing full insights in the domain (De Bruin et al., 2005). Additionally, the model rows need to be populated to indicate how these dimensions progress over the different maturity levels. Both procedural models propose interviews or exploratory techniques such as the Delphi technique or a case study that can be used to populate the developed construct, however, the availability of resources and time available for the team usually determine the method. Therefore, this research has employed the most commonly used technique in maturity mode development being an extensive literature review. It is suggested to extract critical success factors and development criteria from the researched field in order to populate the model with the relevant attributes (Becker et al., 2009). The papers collected during the review are combined within a broad analysis of the field to identify what aspects are relevant for the maturity model and how they relate. This is not limited to academic research, but also includes insights from deployment reports and technical insights.

While the number of levels can be variable, they need to be named and defined distinctively. Specifically, the procedural models argue that the level descriptions should provide a summary of the major requirements and additional elements that need to be present to reach that level. As such, the maturity level descriptions are defined after populating the model and are based on the major changes throughout the levels.

Consequently, combining all these steps, returns a complete maturity model consisting of a fundamental structure, maturity stages and definitions, dimensions of maturity and individual components for each field. However, de Bruin et al. (2005) argue that using the literature review approach, how exhaustive as it might be, is only sufficient as a theoretical starting point for developing a maturity model. To get to a comprehensive and operationalised model, additional testing, evaluating and redesigning steps should be taken.

4.4 Evaluation

After constructing the maturity model and populating it in the design step, the procedural models for maturity model development recommend an evaluation step before the demonstration. Becker et al. (2009) argue this needs to be done before designing the communication from of the model in order to comply with all design science requirements. The established model should be evaluated by experts to ensure the relevancy, and then be redesigned to incorporate the given critique. Evaluating the developed construct can be done on each development stage of the construct. This iterative approach allows researchers to establish if the model achieves the outset goals of the research. For the assessment of the constructed conceptual maturity model, the use of expert interviews is a recommended method by both papers.

As this paper is concerned with providing a holistic theoretical starting point of this domain, collecting insights from literature in this relatively new field, a broad range of experts are interviewed to confirm the plausibility of the model. In this case, the maturity model is assessed by interviewing professionals that have experience with implementing innovative ICT solutions in cities, and more specifically C-ITS projects. Similarly to the approach taken by Becker et al. (2009) for developing the ITPM^3, a semi structured interview approach was taken. This approach leaves space for open answers from the experts in order to allow for the optimal input and focusing on topics important to their personal experience. In order to ensure that everything relevant was consistently assessed, concepts from literature were derived and the interviews were structured based on an interview guideline available in annex A. The interviews have not been analysed quantitatively, due to the limited number of interviewees and the experience-based input which does not lend itself to this (Warnecke et al., 2018).

The procedural models both suggested several elements of the maturity model that should be evaluated in this phase of the model development. They argue that this step is required in order to assess the relevance and rigor of the work focussing on the model validity, generalisability and problem adequacy. Firstly, assessing the validity of the construct means considering both the face and content validity according to de Bruin et al. (2005).

Face validity evaluates the degree to which the model accurately translates the constructs that have been identified within its' scope. Content validity measures how comprehensively the domain is represented, ensuring the theoretical basis is sound. This includes testing the developed construct with the experts, in order to assess if they agree with the dimensions, the maturity levels, as well as the clarity of the concepts. Additionally, the generalisability is evaluated by including the experience of experts from different countries and different types of cities within Europe. This will allow research to identify if there are any indicators or dimensions that are more or less relevant in different contexts across Europe, as well as how dimensions should be defined in order to ensure that level assessments have consistent outcomes. Thirdly, the problem adequacy of the defined model will be assessed to get a better understanding of how and what they perceive as the most pressing problem, and if this model manages to help create an understanding for that.

As this research has been driven by the uneven deployment of C-ITS services across European countries and cities, the interviews are limited to this area. Additionally, the literature was mainly focussed on the development of C-ITS in Europe, considering the important role of EU legislature, directives and projects. As the target group of the model are the broad actors involved in the city development of C-ITS projects, a diverse range of experts were considered. Consequently, several experts with experience in managing and implementing C-ITS projects in various European cities had been contacted via email, and asked to share their experience through an online call. The contacted profiles included technical researchers that have experience with advanced technological projects, public administrators working within transportation departments familiar with C-ITS, project managers that are familiar with the broad implementation challenges and experts that advice authorities and cities for developing transportation systems. After the model design chapter, the results of these interviews will be provided in chapter 6. They will provide insights in the foundation of the model, and the relevance according to experts in the C-ITS field.

Assessing the maturity model aspects does not only serve as an evaluation method for the model, but also allows for identifying new insights on the development of C-ITS services within urban environments. The acquired insights from this will then be discussed in chapter 7, using this to adapt the existing maturity model to the findings and suggest recommendations for further research. Specifically, this unique city oriented approach includes diverse expert experiences, which can provide future researchers with novel insights on C-ITS implementation. Consistent with the procedural models, future research can execute additional iterations in order to develop a final maturity model instrument. Different venues could be taken, including using quantifiable results and incorporating survey input from a big number of practitioners. In order to approach the demonstration phase, the model should then further be operationalised to allow for detailed case applications.

5 Maturity model design

After having discussed the chosen design science approach to this research, described the individual components this process entails, and identified the appropriate methodological practices, this chapter concerns the actual design phase of the maturity model. Each of these individual steps have an impact on the eventual design of the maturity model. As said before, the approach by de Bruin (2005) is taken in developing the different parts of the maturity model. Specifically, the top-down approach is guiding the development process, which after determining the model structure, continuous by identifying what the different dimensions and maturity level descriptions. For this, academic literature is considered which has been described in the literature review before, as well as grey literature from influential institutions and innovative projects due to the novelty of the field and the practical relevance of this topic (Warnecke et al., 2018).

The model is designed to evaluate the maturity of cities in developing and deploying integrated C-ITS technologies. The target audience of cities, which differentiates it from the efforts by Gettman et al. (2017), are defined in the C-Mobile project, as*:* "all those partners belonging to the decision making and road management activities for an urban geographical area" (Lu et al., 2019). The purpose of the model is to collect the relevant factors in the deployment of C-ITS technologies, and allow cities to evaluate their strengths and weaknesses to support improvements. The design strategy to do this is guided by the influential CMMI approach and employs insights from the earlier USDOT CV CMM and SCMAB models touched upon in the literature review. As such, the design strategy is not concerned with developing a completely new model, but basing the structure on existing insights from earlier models, and adapting those to the specific context, audience and novel insights that have been developed since previous models have been created.

The maturity model structure is based on the SCMAB maturity model utilised by Warnecke et al. (2018), as this model covers the same entity being the city. Similarly, the CMMI guidelines are employed for determining the maturity level representation and concepts. Subsequently, the maturity level determination mechanism needs to be established. Maturity is commonly represented as a series of one-dimensional linear stages based on an "average" for the entire entity or a differentiated maturity assessment with complex domains can be chosen using a "stage-gate" approach (De Bruin et al., 2005). The approach for this model is based on the maturity model by Gettman et al. (2017), using something similar to an average approach. They prescribe that the general maturity level can be found by identifying the criteria for each level, when the majority of the criteria under that level have been met, the city is likely on that level, if not it is on the lower level. This approach gives space for a more interpretive approach which accommodates the novelty of the field which makes it harder to define specific criteria according to by Gettman et al. (2017), and works well with the employed top-down maturity model development strategy.

5.1 Maturity model dimensions

Based on the literature barriers and best practices were identified that affect the implementation of C-ITS applications in urban environments. These dimensions form the rows of the model, and are described below in order to provide a clear motivation for the inclusion of each of them based on earlier literature. When both the row and column titles are defined, the description of these individual dimensions will form the basis of the model components based on which cities will be assessed.

Research emphasises the importance of integrated **strategic planning and policy** in implementing and accommodating the technological applications for transportation (Benevolo et al., 2016; Garau et al., 2016; Munhoz et al., 2020; Setyowati et al., 2020). A strategic mobility plan plays a crucial role by creating a holistic view on ITS solutions, translating objectives into goals and creating an integrated vision of all different dimensions of urban living. Consequently, these formulated objectives should then establish a long term vision of the city creating the basis that motivates the use of technologies and determining the selection of which C-ITS services should be implemented. These city guidelines should encourage the development of smart mobility solutions, and provide legal and financial guarantees by signalling the long term needs and investment plans. Additionally, an alignment of public policy and policy targets from central and regional governments creates a more favourable environment, establishing the legal framework to develop these novel services . This needs to bring together the needs of local flexibility of implementation trajectories for these projects in regards to timing, project size and partners, and long term verifiable policies at higher levels (Proskawetz et al., 2013). For mature cities, these plans should employ ways to monitor and evaluate the outcomes, in order to ensure an effective implementation (Garau et al., 2016).

Data sharing strategies and policies are needed for the implementation of C-ITS technologies. As the exchange of data forms the basis of many of the services, policies need to be enhanced that consider use of data and data privacy (Gettman et al., 2017; International Transport Forum, 2020) Data is central to smart mobility and managing and sharing data wisely by establishing data sharing principles helps in ensuring broad mobility benefits. Rules around the gathering and use of data should be clearly established in order to create a secure ecosystem. The complex combinations of public and private actors in new technologies create new challenges. Therefore, the establishment of regional data sharing partnerships allows for the required cooperation in several ITS initiatives, now and in the future. This data sharing relates to users and citizens, the different authorities, research institutes and private companies.

Data protection is regarded as a main security and ethical issue for the implementation of C-ITS projects, as these applications process and monitor personal data systematically from users (Choosakun et al., 2021; Hamida et al., 2015). For that reason, it has been argued that cities should assign a Data Protection Officer to ensure that privacy concerns are respected as well as considering the need to comply with the GDPR, and demonstrating the user consent for using personal mobility data [Castells et all 2018?]. Additionally, this needs to be ensured across all stakeholders involved in order to attain maturity, and remove this barrier for C-ITS technology adoption.

Procurement is important as off-the-shelf-solutions are rarely available, however, it is challenging to do for complex and integrated projects and in many cases can be used more effectively (C-ITS Platform, 2017; Ricci & George, 2014). Complicated tendering procedures with strict and detailed procedures can form barriers to the timely development of C-ITS and innovation, therefore, procurement methods in cities need to be upgraded to ensure value for money in ITS projects. Specific projects such as P3ITS, P4ITS and SPICE have been working on supporting C-ITS procurement, providing better procurement options and providing C-ITS procurement guidelines (Li et al., 2017). This includes introducing a competitive dialogue phase, stimulating cooperation between new and existing suppliers, and choosing open standards and protocols against vendor lock-in. Procurement instruments that are focussed on stimulating innovation and allow for joint procurement, together with the right legal framework and standardised terminology facilitate development.

User involvement has been seen as one of the crucial factors in guaranteeing the success of C-ITS initiatives (Albino et al., 2015; Benevolo et al., 2016; Vrščaj et al., 2020). Authors argue that user involvement is crucial in from the conceptualisation of the future mobility plan, to the development of the services, and the engagement after implementation. For example, Benevolo et al. (2016) warn that while ITS technologies might not be expensive in the introduction phase, there is a risk that they might not be very well accepted by the community. Therefore, an inclusive approach should be taken, involving actors with different perspective. Cities have a mature implementation readiness, once there is a good level of citizen’s involvement and awareness about the potential benefits and opportunities according to Benevolo et al. (2016). Research has argued that a responsible central organisation should push for user involvement based on modern approaches and ensure this responsibility is taken by the relevant actors (Vrščaj et al., 2020).

This dimension includes an important challenge regarding the required **expertise and organisation** for novel C-ITS services implementation (Gettman et al., 2017; International Transport Forum, 2021; Warnecke et al., 2018). Navigating C-ITS projects requires an extensive knowledge of existing services, and diverse competences within a city. Specifically, a recurring challenge has been the lack of earlier examples and best practices in implementing C-ITS projects, therefore, city networks and other initiatives for exchanging information have been playing an important role in the broader implementation of initiatives (Tafidis & Bandeira, 2017). Based on these experiences, knowledge within cities is key, while networks allow for the exchange of crucial information, and further development of capabilities in the public sector (Choosakun et al., 2021). IT is key for cities to build up individual skills of employees, organisational skills and expertise in initiatives that multiple stakeholders. As the required capabilities for this touch on various aspects, it has been argued that multidisciplinary teams that work across siloes are key in deploying smart mobility systems such as C-ITS based on experience from the USDOT.

Stakeholder collaboration is an important part of C-ITS, as these projects involve many actors in the development and operation of the services (Choosakun et al., 2021; Gettman et al., 2017). The collaboration between the different actors need to be facilitated in order to allow for the efficient operation. To efficiently approach this cooperation, the most innovative projects are based on intense public-private cooperation facilitated by the necessary legislation, a pre-defined organisational architecture, and calibrated tools between actors. In many cases research institutions, private and public partners are brought together in a central C-ITS working group to engage all actors, while there is usually one central agency leading the development and collaboration. These initiatives have shown to improve the efficiency of project implementations by creating a common understanding, adopting standards and supporting R&D (Choosakun et al., 2021).

5.2 Maturity model levels

The model structure and respective maturity levels were guided by the CMMI which is an influential standard for maturity model development, similarly to the research by Warnecke et al. (2018). The initial levels were based on the maturity levels proposed in the CMMI, and adapted to the model needs based on the models by Warnecke et al. (2018) and Gettman et al. (2017). The former described city level maturity development of smart urban mobility in general, while the latter provided specific additions to the unique aspects of C-ITS development in transportation organisations. Key here was their approach to adapting the levels to the novel and innovative nature of these technologies, which has been incorporated in the level descriptions for this model. These levels are identified by level names and descriptions, that expand the definition and summarise the main requirements for attaining that level (De Bruin et al., 2005). Therefore, table 3 provides the maturity level names and descriptions for the C-ITS city maturity model.

Important to note is that the maturity levels also include a level 0 which means that there has been no experience with C-ITS projects. These levels are designed to represent the general maturity stages a city can be on for the deployment of C-ITS. The maturity level descriptions follow the findings by Benevolo et al. (2016), stating that cities start with ad hoc small scale pilots that are not repeated, moving to large scale piloting projects that are being monitored, and eventually going to a full scale intelligent system development accepted by the citizens. The complete descriptions are based on the individual dimension, bringing together the most important changes over the levels as well as basing certain elements on the maturity level descriptions for smart mobility by Warnecke et al. (2018). Important to note is that this is a qualitative assessment which does not say cities should aim for highest levels. City authorities should consider their needs and goals in order to set a level target and then move in that direction.

Table 3. Maturity level descriptions

Maturity level	Level description
Level 1 - Initiated	A city where the development of C-ITS is ad hoc driven by individuals without a stable environment or coherent strategy, pilots are hard to repeat
Level 2 - Managed	A city where C-ITS pilots are planned and executed in accordance with policy; governance actions are taken; projects are repeated and monitored; sustained cooperation with SHs overlapping needs are identified
Level 3 - Defined	A city where the needs and prerequisites for C-ITS development are defined & coordinated, under a strategic plan and together with the different SHs. Pilots are integrated and processes are described in standards, tools, and methods
Level 4 - Optimizing	A city where the continuous development of innovative C-ITS services is accommodated and stimulated, supported by adjusted processes and in-house expertise.

Subsequently, these components were brought together in a first maturity model artifact, represented in figure 2. This model contains the best practices and barriers identified in literature by this research and is the result of the first iteration in maturity model development. The components for each row define the different elements that should be present in a city to attain that level. In accordance with the maturity model development process, this artifact is subsequently evaluated using expert reviews. The results of these reviews are explored in the following chapter, and findings from this will feed into the research field in general, and the further development process and possible operationalisation of the maturity model.

Figure 2. Maturity model on C-ITS deployment in cities

	Level 1 - Initiated	***Level 2 -Managed***	***Level 3 -Defined***	***Level 4 -Optimizing***
Level Description	*A city where the development of C-ITS is ad hoc driven by individuals without a stable environment or coherent strategy, pilots are hard to repeat*	*A city where C-ITS pilots are planned and executed in accordance with policy; governance actions are taken; projects are repeated and monitored; sustained cooperation with SHs overlapping needs are identified*	*A city where the needs and prerequisites for C-ITS development are defined & coordinated, under a strategic plan and together with the different SHs. Pilots are integrated and processes are described in standards, tools, and methods*	*A city where the continuous development of innovative C-ITS services is accommodated and stimulated, supported by adjusted processes and in-house expertise.*
Strategic planning & policy	Minimal strategic mobility plan with transport objectives leaving room for C-ITS pilots	Mobility plan and policy, leaving room for C-ITS pilots as strategic opportunities	C-ITS services defined as part of the long & medium term mobility plan, kpis and budget identified	C-ITS development established as part of the city strategic mobility plan, aligned with other level administration
Data sharing	Individual agreements for data sharing for separate C-ITS pilots	Regional data sharing agreements managed	Data sharing principles and standards defined for the exchange of C-ITS data	Regional C-ITS data sharing partnerships including all city actors for enabling data exchange
Data protection	Data protection and privacy is an afterthought of pilot implementation	Data security and privacy commitments between stakeholders	Standards identified for the use of data and user consent.	Data protection officer ensuring complying with privacy and security
Procurement	C-ITS pilot components acquired based on the knowledge of people driving the project	Procurement methods employed that allow for C-ITS pilots.	Facilitated procurement processes that enable the successful acquisition of C-ITS projects	Novel procurement methods that enable C-ITS deployment such as competitive dialogue established
User involvement	Need for user involvement identified during pilot projects	Employing user involvement methods in C-ITS pilots	User involvement processes and methods defined that enable accepted C-ITS pilots	Responsibilities defined for user involvement employing novel methods, with a central competent authority

Expertise & organisation	Needs for organisational changes and expertise defined in public departments	Employing a C-ITS responsible with expertise, and executing organisational change	Accepted organisational change, multidisciplinary expertise is shared over silos	Continued adaptations to novel developed organisational structures for C-ITS, and supporting expertise development
Stakeholder collaboration	Informal pilot program arrangements, ad hoc partnerships (public-public and public-private)	The needs and responsibilities of public-private partnerships have been identified in formal arrangements	Stakeholder architecture defined, Public-private and within government collaborations are standardised.	Novel types of collaboration partnerships are institutionalised, including a multi-agency forum

6 Results

After developing the model, several experts were contacted for the evaluation phase. In the end six interviews were undertaken which combined to 5 hours and 16 minutes of online conversations. The number of interviews that have been taken for evaluating this maturity model, lies within range of other research developing maturity models (Becker et al., 2009; Warnecke et al., 2018). The first part of the interview concerned a self-description of the experts summarised in table 4. The interviewees were from five different European countries, with experience in the smart mobility field, having knowledge of or implemented C-ITS projects in at least one European city or cross-European project. The cities in which the experts have worked, range from medium to big sized and were spread across Europe, ensuring the diversity of the acquired input. These experiences were based on the implementation of various C-ITS services such as variable message signs, traffic light prioritisation, in-vehicle signage and GLOSA for public transport, private vehicles and bicycles as part of city initiatives or EU wide projects. The different aspects of C-ITS projects were covered as best as possible by the inclusion of experts with different backgrounds including a research director, technical director, civil servant and project managers with experience in several aspects of C-ITS projects.

Table 4. Background information on the interviewees

Interviewee	**Organisation**	**Position**
1	City administration	Traffic control centre
2	Research institute	Research director
3	National agency	Technical director
4	City administration	ITS project manager
5	Public-Private organisation	ITS partnership manager and advisor
6	Consultancy	Coordinator mobility data analysis

For the second and third part of the interview, the interviewees were asked to provide constructive feedback to be employed as insights for adjusting the maturity model. This resulted in a valuable evaluation of the theoretical basis, components and problem adequacy described in individual subchapters below. This information will then form the basis of the subsequent discussion of the maturity model, and how this should be taken forward based on the procedural models for developing maturity models. Subchapter 6.1 describes the results of the questions related to evaluating the different identified components in the procedural models starting with the dimensions going to the maturity levels and finishing with suggested additions or missing elements. This chapter concerned the maturity model face and content validity evaluation described in the methodology. Subchapter 6.2 concerned the final objective of the interview related to the problem adequacy and main beneficiaries of the maturity model as a whole.

6.1 Maturity model validity

This part of the interviews concerned the validity of the different concepts included in the model, how they would assess the inclusion of the different dimensions and levels, and if they are described touching on the right elements or if other dimensions should be included. These questions gave insights into the theoretical basis of the model, and what experts consider as crucial in implementing C-ITS projects. The interviews took a structured approach going from the top to bottom of the model dimension, starting with strategy and policy and ending with additional suggestions that were not considered in the current maturity model.

6.1.1 Strategy and policy dimension

All interviewees agreed that the strategy and policy dimension is crucial in the development of the development of transportation systems, and thus C-ITS services. Interviewee 3 underlined the importance of this dimension, and the importance of approaching this as part of a holistic system referring to sustainable urban mobility plans (SUMP):

> *"They [SUMPs] are dealing with making cities or parts of cities more sustainable in all areas, not only mobility. ... If you're doing transport or mobility more sustained and if you're going to green mobility, then every single citizen also needs to adapt his behaviour at least a little bit. And we see currently in all this sustainable urban mobility plans to include as well a stronger mobility, and especially service oriented mobility section."*

Interviewee 5 supported the relevance of mobility plans for cities, however, the interviewee emphasised the importance of higher level authorities supporting these plans and providing a strategy on a higher level in order to ensure the feasibility of implementing C-ITS in smaller cities. Therefore, a mature city in implementing C-ITS requires a strategy and policy that takes into account the city as a system, and is synchronised with higher level initiatives that are crucial to ensure a broad implementation of C-ITS. Additionally, interviewee 1 and 2 emphasised the importance of long term strategic plans and goals in developing C-ITS services, within which the projects should fall. However, interviewee 2 argued that this requires a broader awareness than the political level to put the possibilities of these services on the agenda:

> *"These are things that take years the policy planning they are all politicians, the decision makers at the end. It's really hard for them anyhow to take long term decisions. They're mostly interested for their own term, which is maximum five years, so it needs to be something more than that political pattern. So more it needs to be with a huge push from the city authority itself, I mean, the technical departments that manage traffic needs to push for those things."*

Interviewee 6 supported this need for the technical department to demonstrate the benefit this could provide to a city, by also executing efficiency studies. In a similar regard, interviewee 4 found that: "it's difficult to isolate the strategic planning and policy from the solutions themselves. … the strategic planning and policy kind of follows what has been proven in pilots and in earlier stages". Based on the experience of interviewee 2, these long term strategic plans then also determine the chance of getting the required budget for projects. Interviewee 4 argued that the allocated funding by politicians is an important determinant in taking the deployment steps of C-ITS services in cities, forming an interactive relation between the pilot development, planning and service deployment phases. Therefore, the interviewee argued to incorporate these concepts in the strategy and policy dimension components. Regarding level two and three, the interviewee stated that the strategic plan should go in level two before policy formulation: "first, a strategic plan is formulated for piloting stuff, and then if that goes well, it's kind of deployed more on a policy level, in a way, right." As such, the interviewees provided several additional elements that would benefit this dimension as well as connections that are valuable for the model.

6.1.2 Data sharing and security dimensions

Secondly, the data sharing row was regarded as one of the most important levels by the interviewees, referring to numerous initiatives in Europe on mobility data sharing, but also other domains and the number of partners within cities that are involved here. Specifically, interviewee 3 referred to the so called C-ITS directive that defined the data that needs to be freely shared by authorities so this should already be taking place even before C-ITS services are being implemented and will be more extensive in the future. As the model is focussed on Europe, interviewee 4 argued that the regional level mentioned in this domain is not that relevant, but that European C-ITS standards developed by ETSI and other standardisation bodies should be mentioned regarding C-ITS development.

Nevertheless, on the managed level, the same interviewee noted that this should be done centrally or consolidated as this signifies a higher step for cities. In the experience of interviewee 1, an open data policy implemented by cities where all data is open besides when there are restrictions has been important in this dimension. The interviewee confirmed how cities can then start playing an important part by engaging partners bilaterally, and pulling in valuable data sets to make them openly available or employ them in a useful manner, followed by defining these things as part of general contracts and agreements in order to structurally employ this data and allow for the development of novel services on the defined level. Regarding this data sharing, interviewee 5 stated that dimension is described too limited, because this goes beyond just making data available:

> *"With data, it's not just about sharing data. The data must also always pass the quality test and that must also provide a certain certainty that it is accurate and only then will other parties start using that data, so it is not just simply sharing data sets. At best, in a format that is also recognized in Europe, but there is more to it than simply making it available somewhere. "*

When asked about the data protection dimension, the interviewees agreed it is crucial for these services that are so reliant on the sharing of data. Specifically, as in-vehicle data is regarded as personal data, accessing this data and exchanging this falls under strict regulations. Additionally, for the sharing of in-vehicle data, the data exchange structure is developed with the privacy as a design principle in mind. According to interviewee 3 data privacy is especially crucial in Europe and seen as an added value. The interviewee stated that for C-ITS this dimension should not only be about data security, but also about service security or the truthfulness of the messages: *"So security, it's not only about data security, but it's very much about service security, trustworthiness, standards, for the use of data and, of course, the data protection officer ensuring compliance with privacy and security."* Consequently, this take on data security is in line with the take of interviewee 5 argued data sharing to be about, namely ensuring that the data that is shared is also qualitatively useable. Furthermore, interviewee 3 brought up the difficult responsibility aspect that comes with this, requiring high level international agreements on this which need to be incorporated on the local level.

Interviewee 2 and 4 stated that the first levels included in the model don't exist, cities should always be at level four in this dimension because it is obligatory. Interviewee 2 referred to his experience in implementing C-ITS projects, stating that there is no choice, but that this is obligatory due to national law, including the data protection officer and several other cybersecurity and data protection issues. Therefore, the interviewee argued that even if a city is on level zero in general, it should be at level four for this dimension, indicating that these components do not describe the right evolution. Interviewee 4 described the challenge of defining maturity levels in this dimension as follows:

> *"Data protection is a prerequisite basically, I don't know if there are any levels. I don't think there are any levels as such within that, everybody just adheres to GDPR. So, basically, that is a category you can throw it out. "*

Interviewee 5 argued that the data protection dimension should then be part of the data sharing component, however, also mentioning that this might be less of a concern for pilots but for the actual rollout, everything is required to be GDPR compliant. Consequently, the comments on the data sharing dimension provide clear and mostly consistent insights that should be incorporated.

6.1.3 Procurement dimension

Regarding the procurement dimension, different comments were made by the interviewees. Firstly, interviewee 1 mentioned the challenges with procuring innovative C-ITS services on the initiated level. As referred to in the model, because there are no predefined documents on the usually national level on what to procure, this entails contacting partners to see what exists and touching base with different companies. Special procedures for procuring innovation exist, but are not employed by these cities. Interviewee 5 agreed with this, arguing that technical descriptions still need to be developed for many standard components, however, this will not be identified on the individual city level, but will likely come from a higher level bringing together relevant experts. While not all nations have already established technical specifications for C-ITS services, interviewee 3 noted that recent C-ITS projects such as C-Roads have developed these documents as this is regarded as a big topic. The interviewee agreed with the sequence of the different levels with novel procurement methods necessary for these projects:

> *"So C-ITS is always a little bit I would say changing the world, because in C-ITS the C stands for cooperative. And this cooperation is also valid for procurement, we need to identify how to find both procurement procedures that are open for everyone, and that at the end I receive what I asked for."*

The interviewee confirmed that procurement takes place on the city level, starting for pilots with small procurements of for example three C-ITS stations, going to bigger projects of around five million euros which is still with the city and not handed over to a project manager. Interviewee 2 agreed with the importance of the procurement dimension, but also doubted the influence a city can have here as in the experience of the interviewee, the city needs to follow national laws on transparency and competition issues.

Based on the experience with a living lab where private partners were invited to show their technologies, interviewee 4 argued that the initiated level can start lower without prior knowledge of what is piloted beyond a very basic understand of the idea of the solution or what it is meant to solve. Beyond that, the interviewee argued that the next components were too agnostic of existing EU procurement methods that had been developed for technologically innovative projects which interviewee 3 referred to. Specifically, the SPICE project was mentioned, which went into detail on procurement methods for ITS and C-ITS and how public authorities could procure innovations in this field. Cities are often inventing procedures that already exist, not making use of the developed legal framework according to the interviewee:

> *"And it [the EU procurement directive] states how you should procure different things. It states how you should procure research and development, how you should procure innovation, which is different from procuring research and development. And you can procure standardized, finished product, but not everybody uses those, though, uses that directive, unfortunately. So the level two is still relevant here in procurement."*

Therefore, the interviewee argued that looking for these new methods that are available is done first and then become established and as such suggesting switching the level three and four components. Level three is then about using new procurement methods for the competitive dialogue and for the level four maturity, a city should have the right legal framework or procurement law established to utilize the novel procurement methods in that city.

6.1.4 User involvement dimension

The user involvement dimension was seen as an important dimension by interviewee 2, as it helps in order to ensure the acceptance of the services, but at the same time it is seen as one of the hardest thing to achieve. Based on earlier projects with a high number of users, the interviewee emphasised the need of user involvement and the challenges with engaging a high number of end users:

> *"Somebody needs to identify users that are not necessarily you and me who might drive once a day from home to work once in the afternoon, back home, and then perhaps during the weekend, go for shopping by car, or perhaps go out once a*

week to go to a restaurant or wherever by car. If you target those users it is really difficult to convince them that whatever you provide to them is different than what they already use from Google or TomTom. ... And then there are also other aspects about the environmental benefits about safety, but nobody's paying for those except the European Commission, the central government. So unless you get funds from somewhere, it's very difficult to pay for safety."

So rather than targeting users that drive once a day and barely perceive a benefit, methods to target intensive transport users should be identified such as for example delivery drivers. Concerning the different levels, interviewee 4 mentioned that involvement is important, but nevertheless many projects, small and big, happen without it. On these lower levels, interviewee 1 mentioned that user involvement is not seen as a necessity, and usually depends on the project manager. When methods and guidelines are not defined, the project manager determines if user involvement is required for the specific project and what methods to use. According to interviewee 4, having no user involvement should be seen as level zero, as the interviewee explicitly stated that user involvement should already start on the first level when a project is initiated.

Interviewee 3 had a similar opinion to that of interviewee 4, saying that user involvement needs to be considered on all levels, starting with level one as cities should listen to the needs of their citizens to base the development of new projects on. Moreover, the interviewee argued that the this should also include a dissemination strategy with commitment from the political level:

"You need to convince politicians because all of the cities are driven by politicians and politicians will vote and will accept the technology if it is with huge acceptance at citizens level, so this user involvement and user acceptance and acceptance by decision makers and politicians determine policy in the end. If politicians want to have a safe and modern city and the city which is connected, then the money will be there for all the procurements."

When a city then matures more, interviewee 4 agreed that novel methods should be employed that should be determined for individual C-ITS services. In the end setting KPIs would show that cities are mature in this dimension. This would entail setting a minimum number of user input per project or suggested C-ITS service. KPIs could then be differentiated per C-ITS service in order to provide a more tailored approach to the different needs of these services. Subsequently, the provided comments identify common elements that contribute to the current model which should be reflected in the current construct, however, some differences exist between the approaches to early level user involvement.

6.1.5 Expertise and organisation dimension

Regarding the expertise and organisation dimension, Interviewee 1 supported the need for mature cities to work across departments and emphasised the role of a central enabler for innovations:

> *"The whole of what is ITS and what is really just basic traffic infrastructure is all kind of running through each other, there isn't really one team that tells you this is the ITS team that deals with innovative things. But I think it should be, innovation should be everywhere in your company in all your business and everyone has to work around that. Of course we need some kind of enabler, someone who can pull that off, who has some knowledge that you can turn to if you have a question and that will be provided."*

Interviewee 4 agreed with the different components of the expertise and organisation dimension, moreover, the last level should also consider the different skillset that is needed for continuing services, moving from development skills to asset management, operational skills and those kind of things. As such the interviewee puts a specific focus on the skillset requirements for the different phases. Interviewee 5 agreed that the long term project management skills are difficult to come by, but are important for implementing these C-ITS services. An important role here is assigned to city networks and other C-ITS organisations that provide cities with information on these services and exchange best practices. This observation was shared with many of the interviewees, which regularly attended initiatives by existing city networks or played part in existing organisations.

Nevertheless, Interviewee 2 also warned that public organisations do not need to possess all the skills on how to operate C-ITS, but public-private cooperations need to be considered. According to the interviewee, cities should consider using structures like this to ensure the efficient use of funds facilitate the search for needs and skills a city should possess. As such, it can be seen that the interviewees agreed on the need for this dimension, however, the aspect of outsourcing this expertise as referred to by Interviewee 2 needs to be clarified. Importantly, that topic can be seen as overlapping with the final dimension of the maturity model.

6.1.6 Stakeholder collaboration dimension

Stakeholder collaboration is seen as one of the most relevant dimension based on the interviews. Interviewee 3 strongly focussed on this aspect emphasising the need for clear structures for implementing C-ITS services, but also tying this together with the previous expertise and organisation dimension:

> *"I think here we have a topic in the whole C-ITS, the expertise is less the problem then the governance structures, organizational structures. As I said already, the C stands for cooperative, that means a city cannot deploy C-ITS standalone, there are European rules, there are standards that need to be formed, there needs to be a liaison with other cities, their needs to be a liaison with the motorways. ... So governance structures, organizational structures, those are crucial things not only with the externals but also within city and stakeholder collaboration also included, I need to have my organizational structure and I need to have my stakeholder collaboration."*

The interviewee agreed that this collaboration becomes more important with the increasing levels, also mentioning that clearly described responsibilities and end user support needs to be established. With this collaboration, clear responsibility structures need to be defined in case of any mistakes or accidents.

To be on level four or the optimizing level, interviewee 3 argued it is not only about the transportation system of the city anymore. For example, the incoming motorways need to be connected to this system as well as the application in and interoperability with other cities need to be considered in order to convince other stakeholders. The interviewee argued that this means considering the whole system which requires collaborating in an innovative way and establishing new partnerships to include all stakeholders to attain a more sustainable city. However, interviewee 4 argued that the included element of employing novel collaboration partnerships should be reconsidered. These types of public private partnerships have to be within what is legally allowed and could also be dependent on the different needs for services. Therefore, the interviewee suggested a different emphasis:

> *"I would say this would be a movement from having ad hoc communication with stakeholders, or even just identifying the need for stakeholders. And then going towards having solid frameworks or platforms, or organizations, kind of where stakeholders where you meet regularly with stakeholders and stakeholders meet with each other for these things. So novel types of collaboration, I wouldn't go into like, how novel it is, or how established it is in a kind of legal sense, I would go into the like the regularity and the engagement of stakeholders themselves, that they view that they have an interest into collaborating, and that they do so regularly."*

Concluding, based on the insights of the interviewees on this stakeholder collaboration, this dimension is regarded as being fairly good. As a result of these individual dimension assessments by the interviewees, insights have been provided that confirm or suggest adaptations to the dimensions which should be discussed.

6.1.7 Maturity levels

After having discussed the individual dimensions, the interviewees read through the different levels aggregating the different elements with a thorough understanding of the model content. This allowed the interviewees to assess the content validity of the identified levels and level descriptions. The interviewees agreed that the majority of cities are currently not on the model, but are still in level zero and in many cases unaware of C-ITS services or do not have the staff to consider it:

> *"Cities who are already there, and there are not that many, I mean, there were eight cities in C-Mobile, there might be another eight cities, or ten. So not more than twenty I guess, throughout Europe who are aware of those technologies and for one way or another, either by themselves or because somebody advised them to do so have already started working on C-ITS, investing in C-ITS or have plans to continue doing that. However, there are 10s of 1000s of other cities in Europe, who are at level zero who don't know anything about C-ITS" (Interviewee 2).*

The interviewee stated that this first level starts with another organisation being active within the city on the development of C-ITS. This organisation would provide knowledge and awareness of C-ITS services, or advocate for the implementation of those technologies. Additionally, based on the interviewees experience, each level higher takes a yearlong commitment, therefore, making it impossible that anyone would be on the last level after only working on it for two years for example.

Interviewee 3 argued that the different levels make sense, moving from piloting a C-ITS service, managing the first implementations, and then integrating it into the state of the art making it part of the traditional services. Finally, the interviewee noted that cities should choose if they want to stay on the third level or move to level four in the maturity model. This fourth level, defined as optimizing, was seen as not just concentrating on certain elements of the existing systems and setting KPIs, the city should look beyond that and work differently. The city should be open minded and work on improving the whole system with an emphasis on the collaboration aspect:

> *"What I also see here is that collaboration cooperation is getting bigger, because as soon as I'm coming to level four, thinking about new services, those cities can*

define a new service, a common factor needs to understand the service items. If I have the nicest idea for a service, and all actors say, okay good idea, I will not support you, it will end up lower. So that means more or less level one, two, and three are already in the area of agreed C-ITS services and for level four, I really need to be here on a kind of leading edge and not only optimizing my own system or anything, here I need to cooperate very closely. To cooperate here I need to be highly, highly innovative."

For interviewee 4, the first level description and name seemed quite good, keeping in mind there is a level zero that has no activity happening related to C-ITS as there is nothing going on at that level. After that, the interviewee noted that the description should move from developing pilots in the early maturity levels to the deployment of services in later levels rather than the focus on developing services which is currently being used:

"Level three and level four, you're moving more towards like full scale deployment in the whole city, including service and maintenance. You actually need service and maintenance in the category columns as well, I think because that's the end point. Anyway, you see going from like small scale pilots, ad hoc driven individual, what you call project managers or whatever employees, and then moving towards in the end you simply have deployed standardized, full scale operations services or solutions to use a better word right."

A crucial element for the interviewee to move from the pilot phase to the eventual full scale service deployment is the consistent commitment of funding by politicians for the operation and maintenance of the C-ITS solutions. As such, the interviewees provided valuable insights that could improve the description of the individual dimensions. However, as a final and more general commentary of the interviewees on the maturity model levels, some interviewees argued that the maturity levels might be hard to pinpoint due to the possibility of strongly differentiating dimension performances of cities. Additionally, relations between the defined dimensions can cause issues for the model evaluation. Interviewee 2 described concerns with this evaluation issue as follows:

"On a dimension by dimension case, as I said before, I think the dimensions you have here, some of them are interrelated. But some of them are prerequisites for the others, I think it might be difficult to find the city that his is at level one, for all seven dimensions, or at level four, or anything in between, for all dimensions, it might be pieces here and there."

Therefore, based on the experience of the interviewee, this would mean that the pace for progressing could take different speeds and the general level might be more difficult to determine. Additionally, Interviewee 2 suggested to think more about what the prerequisites are to attain the first level and incorporate these insights. These results should be taken into account, however, the interviewee could not find additional dimensions to add.

6.1.8 Missing elements

Besides assessing the existing components that are part of the maturity model, some of the interviewees also suggested additional elements that are relevant for the topic. When asked if additional dimension should be added, most interviewees agreed that more or less all relevant elements were covered in the model. For interviewee 1, there was nothing completely unnecessary or really wrong to the model that stood out. Similarly, based on the experience of interviewee 2 the model takes into account the elements the interviewee felt as being important, however, noting that everything can be improved and next steps should be taken. However, Interviewee 4 did identify some additional elements which are necessary for the development of C-ITS, but which had not been incorporated satisfyingly. Based on experienced challenges with legacy equipment and infrastructure in C-ITS projects, the interviewee argued for the inclusion of a technical dimension:

> *"I think you lack kind of a perspective on existing equipment, or legacy equipment, because even though, maybe call it prerequisites for C-ITS deployment or something, even though you'd like to deploy some C-ITS, and even though all these things are on a high level, you would still need some technical real world, prerequisites that are necessary. .... Here, if your traffic signals don't communicate, don't even themselves necessarily know how long it will last until the signal changes, then you can be in a very mature level in all those categories, but you're still not capable of deploying C-ITS."*

The interviewee argued technical elements like the infrastructure, technology and their lifecycles determine which data is possible to acquire, and what C-ITS can be deployed in the city. These technical prerequisites are different for the different C-ITS services, therefore, the interviewee proposed this could be differentialized on individual service level descriptions. Interviewee 5 agreed that although C-ITS is often seen as something virtual, there is still an important physical component that needs to be taken into account. For example, a car using lane assistance needs consistent and readable road marking, that meet the needs of the system. The interviewee argued that the need for data and physical component could also be part of the procurement dimension. Different then in the past, now there is a consortium of parties that deliver one service, for which one provides the physical aspect and another the data components which need to be agreed on during the procurement.

Another row suggested by interviewee 4 would be operations described as services and maintenance of the system. This dimension would concern that there are stable service and maintenance agreements, standardised procedures to fix issues or make changes. However, the interviewee followed this observation by stating that these elements could be part of the procurement and expertise and organisation dimension. Lastly, interviewee 5 emphasised the relevance of the legal framework for the maturity model. Europe develops directives for member states which they need to follow, however, they need to develop their individual framework within this. The interviewee noted that these elements are already part of other dimensions, and emphasised some early elements that need to be defined:

> *"I do think that a legislative framework should already define a number of things in the early phase of what format of data to use, which data can be shared, and also simply map the parties with whom they have to talk."*

Based on these remarks, the interview results provide useful information that should be incorporated in the model development. Some of these insights are based on recurring insights from most interviewees while other elements require extra considerations.

6.2 Maturity model problem adequacy

For the final part of the interview, the interviewees were asked about the problem adequacy, namely, if this model could prove useful and who the main beneficiaries and users would be. These insights should help ensure that the maturity model and different concepts within are targeting the right issues, and that they are applicable by relevant target audience. Based on the levels in the model and where the majority of cities are currently at, the interviewees made different conclusions regarding the problem adequacy. For interviewee 1, there is definitely a case for a maturity model like this based on the general experience of cities with incorporating mobility innovations:

> *"If everything had been perfect I would have answered that we were at four. ... So yes, I think so. And certainly with us too we know, well, I think with every city, the way we move now is not the same as 10 years ago and will not be the same as in 10 years, so a lot is changing and we have to try as cities keep up with it, but also solve all the acute problems of today. So that's always finding a balance, so that can definitely help. "*

Other interviewees, such as interviewee 2, 3 and 5 stated similar things regarding the limited number of cities that can place themselves on the maturity model already. Therefore, these findings point to a similar direction regarding the existing lack of information in the majority of European cities and the need for some kind of a solution. However, based on this, some interviewees noted that this perceived general lack of awareness might diminish the usefulness of the maturity model for these cities. Interviewee 6 regarded the model as a useful checklist to identify where a city should develop itself and define its knowledge gaps, but expressed its concern that this maturity model first requires cities to be on a level where they are aware of existing solutions and available technologies:

> *"I see this whole field more as a kind of supermarket and your model says, this is the map of the supermarket and here you will find the bread, here you will find the meat products, here are other stuff etc.. But you don't start in the store yet, your manual is a map that hangs on the outside of the store and then you and I and other people know how the supermarket works. But for all that ITS stuff, how does that work exactly, that a lot of people don't know so they have no idea what's all for sale. ... And I think that there is a difference in knowledge with small municipalities far behind, I also see that in webinars about these kinds of topics, but not all provinces are equally well informed either."*

Therefore, the interviewee argued that the current main concern is related to making cities aware of the existing services and demonstrating their benefits. However, the maturity model or "manual" would not convince cities to start C-ITS projects, "If you do not know what you do not know it becomes very complicated." Interviewee 5 even stated that: "I think it's useful to see what steps are needed, but I think if you gave it to some cities today, it might also deter them because they aren't very developed in that respect." According to this reasoning, showing the requirements would make cities focus on the resources, processes and knowledge they lack, rather than embrace the benefits of the C-ITS services. Similarly to these observations, interviewee 2 stated that because the maturity model starts at level one:

> *"Your target group then starts from those cities that are already somehow aware of those technologies are somehow aware of the benefits and are somehow aware of the costs, and seem to have some incentives to work with those technologies, either by themselves, or somebody next to the city, a private company, a research centre, a consulting company."*

Therefore, interviewee 2 also argued that it is important to make the case for why cities should invest in C-ITS. Especially because cities often already have traditional traffic management technologies for which they pay millions every year in maintenance. Additionally, the interviewee discussed that C-ITS technologies were originally not meant as a service directly to the user, but have been repurposed due to the slower than expected development of automated vehicles:

> *"C-ITS are technologies and services which are mostly focused on vehicles that still do not exist. So the information for the C-ITS services is not supposed to be shown to the driver, it is supposed and it is meant, this is why it follows standards to go to the onboard computer of the vehicle and assist the vehicle in navigating by itself."*

Following that, the interviewee argued that cities in itself will not be attracted to these novel technologies without the right incentives, awareness of costs and broad dissemination of knowledge. Moreover, interviewee 5 noted that including experiences of other cities in the maturity model would help the earlier mentioned deterring of cities by the unclarity and unawareness of existing projects in the field: "So if you could provide examples of all of those things of that city has done it like this and those were the experiences, then you will get further into it." However, printing the model as it is and sending it to cities to point them out their strengths and weaknesses without providing assistance or best practices would not help in attaining the set out goal of the model.

Consequently, interviewee 5 argued that including best practices from other cities in the maturity model to support them would enhance the accessibility of the model, and enable the sharing of experiences which usually happens during demos and city visits. The interviewee stated that this is more difficult to do for smaller cities due to limited budgets and manpower. However, not all interviewees put that big of a focus on the issue of creating awareness for these innovations and the challenge of convincing cities to attain level one. Interviewee 3 expects that all cities will eventually achieve level one, and describes this evolution as follows:

> *"Single cars will be equipped with C-ITS, it will happen with or without the cities, that's reality, there will be connected cars. And the big question towards the city authorities is do you want to be part of the whole system? Do you want to get data? Do you want to get information? Do you want to get better knowledge about mobility in your city? Then you should become part of C-ITS, if not, everything is fine C-ITS will happen with or without cities."*

The interviewee also stated that certain C-ITS applications are used for traditional services in cities such as parking information or restricted access, and most of these cities are in the learning phase. Consequently, the interviewee argued these services are not focussed on promoting the individual car use, but they are currently mainly used for public transport and emergency vehicles. The concern if C-ITS services and thus this model are relevant for cities that base their mobility vision on a shift away from individual cars is a concern shared with multiple interviewees. For example, for the city of interviewee 1 the priority is less on ITS innovations as they are usually found to focus on the motorised vehicle while their priority is on local mobility plans. However, the experience of interviewee 4 found that a focus on more sustainable forms of transportation and decreasing carbon emission can benefit from C-ITS:

> *"For that purpose, we try to move as many people from cars in a way that's not intrusive in their lives necessarily, but by adding additional services for cyclists for example, and improving convenience in general for cyclists, which we believe is the way of doing it. ... So that's kind of the behavioural mindset in many of our projects, which also kind of permeates the ideas with the technical deployments or the technological deployments that we're doing."*

In developing these services for road users such as cyclists, the interviewee argued its city to be quite innovative, placing it between level two and three of the maturity model and agreeing with the applicability to the problematics of the city. Concluding, the different responses have shown that there is some discussion in what should be the priority to tackle for C-ITS and the existence of a lack of awareness. These different outcomes from the interviews provide interesting insights and recommendations which should be considered in the next chapter. Subsequently, the interviewees were then also asked who would be the main users and beneficiaries of this tool.

As mentioned before, interviewee 1 argued that the tool could benefit cities, helping them keep up with the constantly developing transportation field. Interviewee 2 supported this view, but suggested some additions to the maturity model to make it more useful for cities and support cities in their strive to progress through the different levels:

> *"But let's assume that the city wants to improve overall, traffic related issues, so what are the costs from going, or first of all, which are the cost categories? And then perhaps, some ranges of course not necessarily concrete numbers, but ranges of costs, types of costs and the rates of costs to go from one level to another and perhaps also a time horizon for that. So in order to go from level one to level two, you need three years and 10 million?"*

For interviewee 3, the maturity model would be most useful for smaller cities and cities that are currently not involved in C-ITS. Cities on level one or two would already be familiar with the different elements in C-ITS and have already committed to projects. However, for other cities that are considering starting, the model gives them a clear idea of the paths they should take, and the different dimension that need to be covered in these projects such as considering privacy and the needs for collaboration. Interviewee 5 was more sceptical about this, mentioning that this would require examples of best practices, not too deter cities. Therefore, the interviewee stated that the maturity model could be best employed on a higher, provincial level or possibly in big cities that have the necessary knowledge and means. Other interviewees agreed that this tool should not necessarily be used by cities themselves, but could help higher level organisations, by providing a general evaluation method. Interviewee 4 first referred the use for EU level institutions, stating that:

> *"It should be a central kind of a central organ, a city itself can of course, evaluate itself and that could be quite useful, but it's only interesting once you have multiple cities doing it, and kind of gauging the levels to be able to kind of know where funding should flow to in a way."*

Moreover, the interviewee argued that nations with an interest in developing C-ITS could employ the maturity model to assess which dimensions need to be addressed and which cities should funds be allocated to from a central organization. For interviewee 6 this goes back to the lack of awareness for individual cities:

> *"So for the sector, for the advisors for the experts, it is very nice and pleasant to have such a map to be able to interpret it yourself. Hey I don't know much about this subject yet, maybe I should take a look at it too deepen my knowledge. And that will be for people who are really involved with that theme, at road authorities, provinces, but then you have to be into it to some extent, you have to know what you don't know."*

Therefore, the interviewee supports the view that the maturity model is mainly useful for road operators or provinces rather than individual cities. Concluding, the interviews described several aspects of the maturity model that help take on the challenges with C-ITS implementation in cities. However, a heterogeneous picture of the target group that would mainly benefit from the maturity model has also been identified. These results are used in the next chapter for the discussion of the maturity model within the broader field of developing C-ITS services in cities.

7 Discussion

The discussion of the results covers to what extent the research goal has been reached of developing a relevant first iteration maturity model, and what adaptations are to be incorporated based on these insights. This includes assessing the successfulness of the developed concepts within the maturity model, and in how far this tool is able to support the development of C-ITS in cities.

Based on the research by Faria et al. (2017), the development of more sustainable transportation systems has become a main concern for cities that are looking to become more liveable by amongst others reducing pollution, congestions and increasing safety. In this strive, cities have begun using more technologically advanced solutions to enable a modal shift and more efficiently use infrastructure, benefitting from developments in ITS and the potential of novel C-ITS services (Tafidis & Bandeira, 2017). However, the question on how to develop these services has gone beyond simply defining policies, but authorities need to consider various elements to be successful (Choosakun et al., 2021).

The budget constraints cities are facing and the financial and organisational efforts that come with these projects have a profound impact on the deployment on these projects to create more sustainable transportation systems. Therefore, the need for evaluation tools to measure the success of the deployment of smart mobility systems has been identified and indicators and maturity models have been developed to measure the end result of such projects (Garau et al., 2016). Specifically maturity models have been proposed as they help assess a city's maturity, provide common ground for cities to assess their situation to determine what requires change and benchmark themselves against other cities. However, research proposing such maturity models then also argued that certain elements can lack in cities which obstruct the successful implementation of these projects (Houghton et al., 2009). Consequently, the case was made for evaluation methods that focus on just that, supporting the deployment of smart mobility technologies by identifying the aspects that need to be present for this, effectively evaluating if cities are ready for C-ITS (Gettman et al., 2017).

This is where the proposed maturity model for C-ITS deployment in cities comes in, which establishes a comprehensive overview of the relevant elements for developing C-ITS in a city, and the maturity stages cities can find themselves on. This model provides best practices for C-ITS deployment to cities and suggests ways for them to develop further in that respect, filling the identified knowledge gap. The model is based on scientific research and combines this in a comprehensive overview that can be used by cities, bridging the gap between academics and practitioners. The goal of this research has been to develop this model, guided by existing procedural models for maturity model development, to provide cities with a valuable tool in their strive for more sustainable transportation system by making use of novel C-ITS services. Considering that this research undertook the first model iteration identified by Becker et al. (2009), covering the initial design phase and first evaluation step, which should subsequently be followed up by further development phases. Therefore, the interviews provide insights into the aggregated concepts in the model and the problem adequacy based on which model development can be taken forward.

7.1 Model features

As stated before, the research goal was to provide a tool that aids with the current issues in developing C-ITS services in cities. Based on the research by Charles et al. (2011), maturity models have been employed in the transportation field to resolve similar challenges, providing several features that support the utilisation of the tool. Firstly, regarding the provision of a comprehensive model that brings together the different components defined in literature, the interviewees were interested, supporting the idea and confirming the challenge that they currently perceive. Although the current lack of general awareness about these services in in cities, and the challenge to improve this was referred to by several interviewees as a first obstacle to deploying C-ITS in cities, the maturity model provides a useful tool to inform cities about the individual dimensions they need to take into account. Subsequently, the results showed that two different logics were followed to identify who the main beneficiaries are, depending on the interviewee perception of the expected general development of C-ITS in cities.

One logic found that as C-ITS will become omnipresent, and cities will have to either choose if they want to benefit from it or ignore the valuable information that is being made available, small cities would be the main beneficiaries as they lack the inhouse knowledge to be aware off all the required elements. Therefore, the maturity model would be extra useful for smaller cities enabling them to improve their transportation systems and benefit from new services. This corresponds with the motivation for the maturity model developed by Warnecke et al. (2018), which had the goal to enable all cities to easily do such an assessment to help them develop a strategy to improve the smartness of their transportation systems. The results also indicated that it was found that for starting cities the maturity model can help them decide which maturity level to strive for and what path to take to do this.

To enhance the usefulness of the maturity model, it was argued in the previous chapter that expected types and ranges of costs and time required to move between levels should be added to the model. This would make the model more informative and practically useful for cities for which these elements are of high concern. However, this information is not commonly part of maturity models that have been developed before. This could be due to broad public for these types of models which make it hard to provide reliable estimations that would not be misleading or unnecessarily deterring. Additionally, another issue to add this information at the moment is that the broad implementation of C-ITS technologies is fairly limited and the field is still strongly developing, making it difficult to find reliable estimates for this which would be prone to changes due to new developments. Therefore, these elements could provide valuable additions, however, future steps will need to assess the feasibility of this and gather the necessary information.

The more generally supported logic in the interviews argues that higher level authorities or big cities will benefit most from this as they have the resources and manpower to look into these technologies and carry the development of C-ITS projects, either by implementing them or by providing the resources and support to a city by a central organisation. Consequently, this covers another feature referred to by Charles et al. (2011), which was regularly mentioned by the interviewees, namely, the functionality of the model to evaluate the current maturity level of cities allowing individual cities to assess their weaknesses, or central authorities to allocate funding or expertise to specific issues of cities. As such, applications of the model are possible by multiple stakeholders, indicating broad benefits. However, maturity model development practices emphasise that such models should be developed based on the needs of the specific target group which should be taken into account (De Bruin et al., 2005).

While smart mobility evaluation tools for urban development like those from Giffinger et al. (2007) or Warnecke et al. (2018) are used to assess the competitive position of cities compared to others, Charles et al. (2011) emphasised the benchmarking functionality. In the case of this model, this means that it can be used to exchange best practices between cities and share knowledge. During the interviews this element of exchanging knowledge through city networks, Webinars and neighbours was identified as being hugely important in developing novel transportation technologies. Therefore, this functionality makes the model specifically useful for supporting a more balanced European wide development of C-ITS services in cities. These findings match other literature in the field of transport technologies, focussing on, and emphasising the importance of, exchanging knowledge on novel transportation ICT solutions between authorities (Cledou et al., 2018; Tafidis & Bandeira, 2017). The results show that the functionality to exchange best practices was supported by the interviewees and even seemed necessary to some, arguing that without practical suggestions for cities to move to higher maturity levels, specifically for cities that are smaller and have less manpower, the maturity model might rather deter than motivate cities to develop C-ITS services.

Therefore, the broad use of the maturity model by different cities would increase the usefulness of the model enhanced by the collection of best practices from cities that would support the knowledge exchange, based on specific needs of a city and without requiring costly field visits. As such the model was also suggested to be used by city networks for knowledge exchange on transportation topics, supporting the applicability of the tool.

One feature employed in the traffic management CMM by Charles et al. (2011), which was developed before as part of the USDOT TSMO CMM, is the specific maturity model additions for individual services. This had not been used in this model, however, it was found in the interviews that several needs of these dimensions would depend on the specific C-ITS services that are looked at to be deployed. Therefore, one interviewee suggested the inclusion of C-ITS service specific parts, which identify relevant dimensions for deploying these specific services and provide individual recommendations to increase the maturity. As such, it is seen as a valuable addition to the proposed maturity model, providing supplemental practically employable recommendations for each service aiding the sharing of best practices between cities and improving their understanding of these technologies. However, similar to the findings of the TSMO CMM predecessor developed by Gettman et al. (2017), the novelty of the C-ITS field makes it hard to develop individual service maturity models. The development of these individual service components has only happened after the services became more standard and conventional with proven deployment methods and technologies. Therefore, this would prove a useful addition to the model once employable documentation exists to further develop this in a generalisable way for the different C-ITS services.

Consequently, the first iteration maturity model for C-ITS deployment in cities is a valuable tool for approaching C-ITS deployment challenges of existing urban transportation systems, covering several features that have been identified in previous research. Specifically, the collection of best practices and challenges from literature in the suggested maturity model structure provide a unique holistic view on the challenges faced by cities. Moreover, it assists cities in setting out steps to improve their overall system, it provides information to decision makers to allocate resources, and helps cities in exchanging knowledge and best practices.

7.2 Component adjustments

The design phase required the development of the individual components of the maturity model based on both academic and grey literature found in the C-ITS field. However, assessing these components found that the progress of several dimensions does not coincide with the correct level, and that attributing one specific level to a city would therefore be hard. Moreover, according to De Bruin et al. (2005) the rows should be autonomous elements that are not interdependent, however, during the interviews it was found that this is not the case for all dimensions. Consequently, this indicates that adaptations to the current dimensions are required to have a useable maturity model.

Concerning the strategy and policy dimension, it was agreed that a mature city has a long term strategic plan which takes into account the city as a system and the strategic plans of other administrations, similarly to what was defined in the model. These results confirm the findings by earlier research emphasising the need for strategic urban mobility plans (Setyowati et al., 2020). Additionally, the interview results suggested that attaining this political interest and commitment can be challenging and is the result of the interaction between city officials and technical departments. However, the link between the strategic plan and policy in the maturity model should be improved, with adapted policies resulting from an existing strategic plan and thus appearing on a later level.

Due to the nature of C-ITS services, data sharing was considered as one of the most important dimensions in this maturity model by the interviewees, which coincides the findings by Badii et al. (2017). City authorities can benefit from standards developed by EU institutions, but also play an important role in the success of the data sharing and should motivate this sharing between all stakeholders from a central position, which should be reflected in the model as noted by the interviewees. Subsequently, data security was seen as crucial, however, the individual dimension itself within the model was largely critiqued by the interviewees. Some argued that there are no levels in data security, while others argued it is a requirement to start with deploying C-ITS services regularly referring to GDPR regulations and other legal requirements. In line with the argument by one interviewee that perceived some dimensions as prerequisite of others, the security dimension will be combined with the data sharing one, on the basis that data sharing is only allowed when the security and privacy of citizens can be guaranteed. Nevertheless, one interviewee argued that these issues are less of a concern in parts of the piloting phase then the actual rollout. Consequently, these insights should be adjusted in the original maturity model.

Besides the data sharing component, the interviewees argued that the inclusion of a technical aspect would also be required to evaluate the maturity of a city in C-ITS services development as they are grounded within the infrastructure of a city. Specifically, challenges with legacy technologies and the adaptability of existing systems were argued to be important in the early stages of the maturity model. Eventually, a mature city would develop to integrated systems that are continuously updated. Similar elements were included in the CMM CV by Gettman et al. (2017), which would also prove valuable to the current maturity model as the technical components determine what options cities have in developing C-ITS services according to an interviewee. Therefore, it should be considered how these aspects can be included in the current maturity model.

Based on the findings from this research, procurement can be seen as a valuable addition to the maturity model. Similar to arguments by Ricci and George (2014), public procurement can be better used by cities to develop transport technologies. The results from the interviews indicate that the focus should be on just this, arguing that novel technology procurement methods incorporating the cooperative aspect have been developed on higher levels and are mainly determined by national legislation. However, in a more mature city, these methods are more effectively employed for implementing C-ITS services rather than reinventing the wheel, matching with findings from the covered literature. In the end these methods might be further developed to better incorporate the needs identified by mature C-ITS implementors. Similarly, adjustments to the user involvement dimension were recommended, in line with the call by Vrščaj et al. (2020) to take an inclusive approach to the development of innovative transportation services and establish this as a necessary component considering KPIs to ensure this.

The final two dimensions, stakeholder collaboration, and expertise and organisation, were regarded by the interviewees as appropriate and well described in the maturity model, confirming the relevance of these components which supports the findings from literature and the practical application of these insights in the model. Considering the expertise and organisation dimension, one interviewee emphasised the importance of change in the necessary skillsets for implementing C-ITS. At first, to develop pilots project managers should be employed that have the necessary development skills for new services, once these services are then established as part of the transportation system in the city, people with maintenance, operational and asset management skills are required to manage the broadly implemented services. While it was argued this could form an individual dimension, this paper argues that these elements should be represented in the expertise and organisation dimension. Importantly, a city needs these skills to have an operational system, however, this does not mean that each city needs to possess all these capabilities, but parts of this can also be outsourced to private partners as was the case for one of the interviewees.

A recurring topic throughout the interviews was the challenge to get the required political support in developing C-ITS in cities, and the budgetary component for C-ITS development and long term deployment. Arguably, these elements could be included within the first strategic planning and policy dimension, as the development of a strategic plan including these services and needed policies reflect a political commitment. Additionally, the inclusion of a novel dimension could be considered. This option could benefit from the approach in the USDOT CV CMM defining a business process capability for the infrastructure owners and operators, which focusses on issues related to planning and budgeting of resources, with the final level having an established CV programme including a budget.

Regarding the four maturity levels established in the model, several adjustments were recommended by the experts. Firstly, attaching the level zero to the model would decrease confusion and visualise a clearer evolution together with the subsequent levels. These suggestions correspond with the model by Warnecke et al. (2018) and the recommended CMMI approach for maturity models rather than the four level CMM approach in the model presented by Gettman et al. (2017) for the USDOT. Additionally, one interviewee argued that the evolution of C-ITS deployment should be better represented in the maturity level descriptions. Specifically, the mention of pilots and the word choice between deployment and development throughout the descriptions resulted in comments. Firstly, the interview results match with the findings by Choosakun et al. (2021) which argue that deploying pilots in limited areas enable the large scale deployment of C-ITS services. Therefore, as the model is concerned with C-ITS deployment, the description should be adjusted to include this progression to large scale implementations. Secondly, similarly to the survey findings by Benevolo et al. (2016) on the evolving path in Smart Mobility actions, in the later levels of C-ITS deployment, the focus should be on the deployment of services rather than first developments, indicating that cities are mature in employing the related technologies. Therefore, the second last level should focus on the deployment of C-ITS services, and the final level being on optimising and further developing an existing deployed transport system. Consequently, the comments from the interviewees provided useful insights to the initial maturity level descriptions.

Concluding, the interviewees made several suggestions on how to adapt the current maturity model components that were based on literature. Most notably, the combination of the data security and sharing dimension were recommended, and an additional dimension covering the technical component was proposed. Moreover, several smaller adjustments throughout the model dimensions and levels could make it more reflective of reality. As such, these comments feed into the iterative development process of maturity models by Becker et al. (2009) and De Bruin et al. (2005) that have been followed in this research, creating a fruitful basis to enable future enhancements.

8 Conclusion

The research carried out in this paper was motivated by the developments in transportation technologies with innovative projects being carried out across the world and several C-ITS services becoming mature. The broad deployment of these services in Europe is seen as a next milestone to the development of CCAM, and is argued to bring several benefits to transportation systems including an increased security, efficiency, and comfort (European Commision, 2016). Specifically, cities are set to benefit strongly from these services, as they are at the forefront of developing more sustainable transportation solutions, and these new data streams are argued to play an important role in becoming smart cities. However, research has found that several challenges still exist that prevent the broad deployment of C-ITS services across cities which is causing a heterogenous development across Europe (Lu et al., 2018).

For those reasons, the goal of this research has been to develop a maturity model to help city authorities assess their current environment for implementing C-ITS services. This involved applying a design science research approach to develop this artifact, tailoring this to the development of a maturity model by following the maturity model development frameworks by Becker et al. (2009) and de Bruin et al. (2005). The model design phase built on previous applications of maturity models in the transportation field. Subsequently, the individual dimensions were defined and the maturity model was populated based on earlier research in the young C-ITS field, including grey literature and project papers, describing best practices, barriers and challenges they face. Subsequently, six experts were consulted in individual interviews during the evaluation phase, providing their insights on the dimensions, model validity and problem adequacy.

This research found that the identified dimensions succeeded in covering most of the unique and novel challenges cities are facing when developing and deploying C-ITS services. Therefore, it contributes to recent efforts to aggregate insights from transport innovation research by providing a unique comprehensive overview of challenges for C-ITS development in cities. Moreover, the individual dimension evaluation led to the identification of additional elements that should be incorporated in the suggested model, and specific considerations that should be made in this field.

The emphasis of earlier research on the strategy planning and policy aspect was confirmed in this research. However, the role of technical departments in making policy makers aware of C-ITS services and other innovations was emphasised, which was not covered in the considered literature. Secondly, data security and privacy was regarded as a prerequisite for data sharing, arguing that in a European context, several legal concerns need to be covered before starting projects that share data such as the GDPR. While this was attributed to the European context, it was also argued this approach is being exported to other areas in the world, therefore, it would be interesting to research the regional differences for C-ITS projects. Thirdly, it was found that the focus of the maturity model was too much on the digital aspect while C-ITS also relies strongly on the existing infrastructure. Therefore, a technical component was suggested that cover elements such as legacy systems, standardisation, modularity and interoperability, which should be further developed based on the existing literature on this topic.

User involvement and procurement were seen as highly relevant, with both dimensions having their own specific challenges which occur continuously in numerous cities. The former is regularly not included, while it is crucial for user acceptance which makes a mature transportation system, and the latter is often reinvented to allow for the cooperative aspect while tools and regulations have already been developed. Similarly it is this cooperative aspect of C-ITS which makes stakeholder collaboration an important element of the model. Establishing sustainable ties with the different stakeholders within C-ITS projects was seen as crucial, especially in such a complex environment as city transportation systems which can strongly differ between cities. As such, expertise and organisation challenges for these city authorities has been identified as important, but also heterogenous between cities. Therefore, the generalisable approach that allows cities to evaluate this based on their needs and experience is regarded as beneficial.

These results indicate that a maturity model to assist cities with evaluating their readiness in deploying C-ITS would be a useful tool to take on an existing problematic. Specifically, the interviewees brought up several reasons why the model would be a helpful tool in assisting C-ITS deployment. Firstly, the identified path gives cities a better idea of the requirements for C-ITS deployment, and allows them to make more substantiated decisions on how to take this forward. Secondly, the benchmark functionality supports the knowledge exchange efforts that have been made in this field by identifying best practices across cities. Thirdly, higher level governments and centralised organisations are expected to benefit strongly from this functionality, helping them in assessing and comparing the state of several cities in a generalised manner, which could provide the basis for assistance and budget allocations.

However, it was found that a currently more challenging aspect to C-ITS deployment, was the lack of awareness with cities. Most cities are argued to be on level zero, never having considerd C-ITS services so far. Therefore, future research should look into how this awareness could be increased, and how C-ITS services could be made more accessible for cities that lack high transportation budgets and manpower. Moreover, this research covered the first iteration in maturity model development. Based on the procedural frameworks followed, additional steps are prescribed before such a model can be operational for practitioners. As such, future research could continue the top-down approach, using the findings of this paper to redesign the maturity model, and formulate more specific measures and questions. This would include additional evaluation steps such as the application of this model to multiple cases and survey with the target audience. Consequently, the current maturity model provides a useful conceptual first iteration which can be taken forward in future research to attain an operationalisation.

It should be taken into account that there are also some limitations to the research approach taken in this paper. Firstly, methodology wise this research has been constrained by the available time and resources of the researcher which is reflected in the chosen methods and subsequent results. For the maturity model design, a literature review was used to identify the different elements which is put forward by both procedural frameworks as a regularly employed method. However, additional exploratory research methods such as the Delphi method are recommended for the design phase which could provide deeper insights. For the evaluation phase, the number of experts interviewed is at the lower end of the preferred input (Becker et al., 2009; Warnecke et al., 2018). As the interview responses started to reappear, this does indicate that the results became representative of the general perception of the field, however, additional interviews with a more diverse group could provide richer insights into the various aspects. Nevertheless, these methods lie within the scientific approach suggested, indicating that the approach taken is scientifically sound.

Secondly, the geographical focus on European experts should be kept in mind when transferring insights from this model to other regions. Specifically, the unique legislative, standardisation and network aspects need to be taken into account, as well as the different cultural aspects. This scope has allowed for the incorporation of specific insights of this area, however, adapting the model to other regions would benefit from additional interviews. Lastly, C-ITS services and the transportation field in general are quickly developing with new applications being tested for various aspects of transportation systems. Therefore, it needs to be kept in mind that this research is only a snapshot of the current state of the field, which can be affected by changing views on various elements or new needs of novel technologies. Consequently, the C-ITS field is still in motion, providing valuable opportunities to contribute to the research field and enable cities and their inhabitants to benefit optimally from this progress.

References

Alam, M., Ferreira, J., & Fonseca, J. (2016). *Introduction to Intelligent Transportation Systems*. https://doi.org/10.1007/978-3-319-28183-4

Albino, V., Berardi, U., & Dangelico, R. M. (2015). Smart Cities : Definitions , Dimensions , Performance , and Initiatives. *Journal of Urban Technology*, *0*(0), 1–19. https://doi.org/10.1080/10630732.2014.942092

Allsop, R. E. (2006). *Some reflections on forty years' evolution of transport studies*.

Asselin-Miller, N., Biedka, M., Gibson, G., Kirsch, F., Hill, N., White, B., & Uddin, K. (2016). *Study on the Deployment of C-ITS in Europe: Final Report.* https://ec.europa.eu/transport/sites/transport/files/2016-c-its-deployment-study-final-report.pdf

Badii, C., Bellini, P., Cenni, D., Difino, A., Nesi, P., & Paolucci, M. (2017). Analysis and assessment of a knowledge based smart city architecture providing service APIs. *Future Generation Computer Systems*, *75*, 14–29. https://doi.org/10.1016/j.future.2017.05.001

Becker, J., Knackstedt, R., & Pöppelbuß, J. (2009). Developing Maturity Models for IT Management. *Business & Information Systems Engineering*, *1*(3), 213–222. https://doi.org/10.1007/s12599-009-0044-5

Benevolo, C., Dameri, R. P., & Auria, B. D. (2016). Smart Mobility in Smart City. *Empowering Organisations*, *11*, 315. https://doi.org/10.1007/978-3-319-23784-8_2

Blokpoel, R. (2019). *Open cloud architecture for connected C-ITS services Paper ID EU-TP1089 Open cloud architecture for connected C-ITS services*. *September 2018*.

Bray, D. J., Taylor, M. A. P., & Scrafton, D. (2011). Transport policy in Australia — Evolution , learning and policy transfer. *Transport Policy*, *18*(3), 522–532. https://doi.org/10.1016/j.tranpol.2010.10.005

Browne, D., & Ryan, L. (2011). Comparative analysis of evaluation techniques for transport policies. *Environmental Impact Assessment Review*, *31*(3), 226–233. https://doi.org/10.1016/j.eiar.2010.11.001

Burns, L. D. (2013). A vision of our transport future. *Nature*, *497*(7448), 181–182.

Butler, L., Yigitcanlar, T., & Paz, A. (2020). Smart urban mobility innovations: A comprehensive review and evaluation. *IEEE Access*, *8*, 196034–196049. https://doi.org/10.1109/ACCESS.2020.3034596

C-ITS Platform. (2017). *C - ITS Platform Phase II: Cooperative Intelligent Transport Systems towards Cooperative Connected and Automated Mobility*. http://ec.europa.eu/transport/themes/its/doc/c-its-platform-final-report-january-2016.pdf

Çaldağ, M. T., & Gökalp, E. (2020). Exploring critical success factors for blockchain-based intelligent transportation systems. *Emerging Science Journal*, *4*(Special Issue), 27–44. https://doi.org/10.28991/esj-2020-SP1-03

Caragliu, A., del Bo, C., & Nijkamp, P. (2011). Smart cities in Europe. *Journal of Urban Technology*, *18*(2), 65–82. https://doi.org/10.1080/10630732.2011.601117

Charles, P., Ferreira, L., & Galiza, R. J. (2011). Improving traffic systems strategy and operations using a capability maturity approach. *ATRF 2011 - 34th Australasian Transport Research Forum*, *September*.

Choosakun, A., Chaiittipornwong, Y., & Yeom, C. (2021). Development of the cooperative intelligent transport system in Thailand: A prospective approach. *Infrastructures*, *6*(3). https://doi.org/10.3390/infrastructures6030036

Cledou, G., Estevez, E., & Soares Barbosa, L. (2018). A taxonomy for planning and designing smart mobility services. *Government Information Quarterly*, *35*(1), 61–76. https://doi.org/10.1016/j.giq.2017.11.008

Crosby, P. (1979). *Quality is Free: The Art of Making Quality Certain* (Abridged e). Mcgraw-Hill.

De Bruin, T., Rosemann, M., Freeze, R., & Kulkarni, U. (2005). Understanding the main phases of developing a maturity assessment model. *ACIS 2005 Proceedings - 16th Australasian Conference on Information Systems*.

Dimitriou, H. T., & Gakenheimer, R. (2011). *Urban transport in the developing world: A handbook of policy and practice*.

Dudley, G., & Preston, J. (2013). Historical Narrative and the Evolution of Academic Transport Studies in the UK. *Transport Reviews*, *33*(2), 131–147. https://doi.org/10.1080/01441647.2013.784375

ESCAP, U. (2017). *DEVELOPMENT OF MODEL INTELLIGENT TRANSPORT SYSTEMS DEPLOYMENTS* (Issue December).

European Commision. (2016). *A European strategy on Cooperative Intelligent Transport Systems, a milestone towards cooperative, connected and automated mobility* (p. 12).

European Commission. (2007). *Green Paper - Towards a new culture for urban mobility*. http://ec.europa.eu/transport/urban/urban_mobility/green_paper/green_paper_en.htm

European Commission. (2017). *European Urban Mobility: Policy Context*.

Faria, R., Brito, L., Baras, K., & Silva, J. (2017). Smart mobility: A survey. *Internet of Things for the Global Community, IoTGC 2017 - Proceedings*. https://doi.org/10.1109/IoTGC.2017.8008972

Garau, C., Masala, F., & Pinna, F. (2016). Cagliari and smart urban mobility: Analysis and comparison. *Cities*, *56*, 35–46. https://doi.org/10.1016/j.cities.2016.02.012

Gettman, D., Burgess, L., Flanigan, E., & Lockwood, S. (2017). *Guidelines for Applying Capability Maturity Model Analysis to Connected and Automated Vehicle Deployment* (Issue November).

Giannopoulos, G., & Munro, J. F. (2019). *The accelerating transport innovation revolution: A global, case study-based assessment of current experience, cross-sectorial effects, and socioeconomic transformations*. Elsevier.

Giffinger, R., Fertner, C., Kramar, H., Kalasek, R., Milanović, N., & Meijers, E. (2007). *Smart cities - Ranking of European medium-sized cities* (Issue January).

Gottschalk, P. (2009). Maturity levels for interoperability in digital government. *Government Information Quarterly*, *26*, 75–81. https://doi.org/10.1016/j.giq.2008.03.003

Hadi, M., Iqbal, M. S., Wang, T., Xiao, Y., Arafat, M., & Afreen, S. (2019). *Connected Vehicle Vehicle-to-Infrastructure Support of Active Traffic Management*.

Hamida, E. Ben, Noura, H., & Znaidi, W. (2015). Security of cooperative intelligent transport systems: Standards, threats analysis and cryptographic countermeasures. *Electronics*, *4*(3), 380–423. https://doi.org/10.3390/electronics4030380

Hensher, D. A. (2018). Tackling road congestion – What might it look like in the future under a collaborative and connected mobility model ? *Transport Policy*, *66*(February), A1–A8. https://doi.org/10.1016/j.tranpol.2018.02.007

Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design Science in Information Systems Research. *MIS Quarterly*, *28*(1), 75–105.

Houghton, J., Reiners, J., & Lim, C. (2009). *Intelligent transport: How cities can improve mobility*.

Humphrey, W. S. (1988). Characterizing the Software Process: A Maturity Framework. *IEEE Software*, *5*(2), 73–79.

International Transport Forum. (2020). *Leveraging digital technology and data for human-centric smart cities: The case of smart mobility*.

International Transport Forum. (2021). *ITF Transport Outlook: Executive Summary*. https://www.itf-oecd.org/sites/default/files/transport-outlook-executive-summary-2021-english.pdf

Kaparias, I., Zavitsas, K., Bell, M. G. H., & Tomassini, M. (2010). State-of-the-art of urban traffic management policies and technologies. *Isis*, *13*(1), 08.

Kim, J., Moon, Y.-J., & Suh, I.-S. (2015). Smart Mobility Strategy in Korea on Sustainability , Safety and Efficiency Toward 2025. *IEEE Intelligent Transport Systems Magazine*, *7*, 58–67.

Kotsi, A., Member, E. M., Tzanis, D., Kotsi, A., Member, E. M., & Tzanis, D. (2020). *Overview of C-ITS Deployment Projects in Europe and USA*. *2020*(September), 1–15.

Li, Y., Raghi, B. N., & Kapl, B. (2017). Using Public Procurement as an Instrument for Implementation of ITS. *12th ITS European Congress*, *June*, 19–22.

Lu, M., Castells, J., Hofman, P., Blokpoel, R., & Vallejo, A. (2019). Pan-European deployment of C-ITS : the way forward. *EU-TP1815*, *October*, 21–25.

Lu, M., Turetken, O., Adali, O. E., Castells, J., Blokpoel, R., & Grefen, P. (2018). Cooperative Intelligent Transport Systems (C-ITS) deployment in Europe: Challenges and key findings. *25th ITS World Congress*, *September*, EU-TP1076.

Mangiaracina, R., Perego, A., Salvadori, G., & Tumino, A. (2017). A comprehensive view of intelligent transport systems for urban smart mobility. *International Journal of Logistics Research and Applications*, *20*(1), 39–52. https://doi.org/10.1080/13675567.2016.1241220

March, S. T., & Smith, G. F. (1995). *Design and natural science research on information technology*. *15*, 251–266.

Marsden, G., & Reardon, L. (2017). Questions of governance : Rethinking the study of transportation policy. *Transportation Research Part A*, *101*, 238–251. https://doi.org/10.1016/j.tra.2017.05.008

Meakin, R. (2004). Urban Transport Institutions. In *Sustainable Transport: A Sourcebook for Policy-Makers in Developing Cities* (Issue December).

Miguel, B. P., Ferreira, F. A. F., Banaitis, A., Banaitienė, N., Kavaliauskienė, I. M., & Falcão, P. F. (2019). An expanded conceptualization of "Smart" cities: Adding value with fuzzy cognitive maps. *E a M: Ekonomie a Management*, *22*(1), 4–21. https://doi.org/10.15240/tul/001/2019-1-001

Mitchell, W. J. (2007). Intelligent cities. *UOC Papers*, *5*(October 2007), 3–8.

Mitsakis, E., Kotsi, A., & Psonis, V. (2020). *C-ITS bundling for integrated traffic management*. 1–15.

Moore, T., & Pulidindi, J. (2011). *Understanding Urban Transportation Systems*. 22.

Mozos-blanco, M. Á., Pozo-menéndez, E., Arce-ruiz, R., & Baucells-aletà, N. (2018). The way to sustainable mobility. A comparative analysis of sustainable mobility plans in Spain. *Transport Policy*, *72*, 45–54. https://doi.org/10.1016/j.tranpol.2018.07.001

Munhoz, P. A. M. S. A., Dias, F. da C., Chinelli, C. K., Guedes, A. L. A., Dos Santos, J. A. N., E Silva, W. da S., & Soares, C. A. P. (2020). Smart mobility: The main drivers for increasing the intelligence of urban mobility. *Sustainability (Switzerland)*, *12*(24), 1–25. https://doi.org/10.3390/su122410675

Neirotti, P., De Marco, A., Cagliano, A. C., Mangano, G., & Scorrano, F. (2014). Current trends in smart city initiatives: Some stylised facts. *Cities*, *38*, 25–36. https://doi.org/10.1016/j.cities.2013.12.010

Nijkamp, P. (2006). IN SEARCH OF A TRANSPORT POLICY RESEARCH

AGENDA. *Journal of Transport Economics*, *33*(2), 141–167. https://www.jstor.org/stable/42747797

Nolan, R. L. (1979). Managing the Crisis in Data Processing. *Harvard Business Review*, *57*, 526–542.

OECD. (2002). *OECD Guidelines towards Environmentally Sustainable Transport*. https://doi.org/10.1787/9789264199293-sum-zh

Ongkittikul, S., & Geerlings, H. (2006). *Opportunities for innovation in public transport : Effects of regulatory reforms on innovative capabilities*. *13*, 283–293. https://doi.org/10.1016/j.tranpol.2005.12.003

Orlowski, A., & Romanowska, P. (2019). Smart Cities Concept : Smart Mobility Indicator. *Cybernetics and Systems*, *50*(2), 118–131. https://doi.org/10.1080/01969722.2019.1565120

Özel, F. M., & Bläsche, J. (2019). Achieving a bidirectional data exchange between central ITS station and traffic management centre : activities within the framework of C-Roads Lower Saxony Pilot Project. *13th ITS European Congress, Brainport, the Netherlands*, *June*.

Paulk, M. C., Curtis, B., Chrissis, M. B., & Weber, C. V. (1993). Capability maturity model, version 1.1. *IEEE Software*, *10*(4), 18–27. https://doi.org/10.1109/52.219617

Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A design science research methodology for information systems research. *Journal of Management Information Systems*, *24*(3), 45–77. https://doi.org/10.2753/MIS0742-1222240302

Plattfaut, R., Niehaves, B., Pöppelbuß, J., & Becker, J. (2011). Development of BPM Capabilities–Is Maturity the Right Path? *European Conference on Information Systems (ECIS)*, 1–13. http://aisel.aisnet.org/ecis2011

Proskawetz, K.-O., Klug, S., & Beckert, B. (2013). *Cooperative Intelligent Transport Systems and Services (C-ITS) - Smart Cities Stakeholder Platform*.

Ricci, A., & George, A. (2014). *Consultation of the Horizon 2020 Advisory Groups Response of the Transport Advisory Group* (Issue June).

Röglinger, M., Pöppelbuß, J., & Becker, J. (2012). Maturity models in business process management. *Business Process Management Journal*, *18*(2), 328–346. https://doi.org/10.1108/14637151211225225

Scholliers, J., van Sambeek, M., & Moerman, K. (2017). Integration of vulnerable road users in cooperative ITS systems. *European Transport Research Review*, *9*(2), 1–9. https://doi.org/10.1007/s12544-017-0230-3

Setyowati, K., Suryawati, R., & Parwiyanto, H. (2020). Planning on Smart Mobility Development. *Jurnal Ilmu Sosial Strategic*, *19*(2), 180–206. https://doi.org/10.14710/jis.19.2.2020.180-206

Shewhart, W. A. (1931). *Economic control of quality of manufactured product*.

Sjöberg, K., Andres, P., & Buburuzan, T. (2017). Cooperative Intelligent Transport Systems in Europe. *IEEE Vehicular Technology Magazine*, *June*, 89–97. https://doi.org/10.1109/MVT.2017.2670018

Sun, L., Li, Y., & Gao, J. (2016). *Architecture and Application Research of Cooperative Intelligent Transport Systems*. *137*, 747–753. https://doi.org/10.1016/j.proeng.2016.01.312

Tafidis, P., & Bandeira, J. (2017). *Interregional European Cooperation platform to promote sustainable transport through ICT – an overview of best practices*. 255–260.

Van Wee, B., & Banister, D. (2016). How to Write a Literature Review Paper ? *Transport Reviews*, *0*(0), 1–11. https://doi.org/10.1080/01441647.2015.1065456

Vannieuwenborg, F., Verbrugge, S., Colle, D., & Degrande, T. (2019). Adoption of Cooperative Intelligent Transport Systems in Flemish passenger cars : a review of European Policy Options. *CTTE-FITCE: Smart Cities & Information and Communication Technology (CTTE-FITCE)*, 1–6.

Vrščaj, D., Nyholm, S., & Verbong, G. P. J. (2020). Smart mobility innovation policy as boundary work: identifying the challenges of user involvement. *Transport Reviews*, *0*(0), 1–20. https://doi.org/10.1080/01441647.2020.1829743

Warnecke, D., Wittstock, R., & Teuteberg, F. (2018). *Benchmarking of European smart cities – a maturity model and web-based self-assessment tool*. https://doi.org/10.1108/SAMPJ-03-2018-0057

Webster, J., & Watson, R. T. (2002). ANALYZING THE PAST TO PREPARE FOR THE FUTURE: WRITING A LITERATURE REVIEW. *MISQ Quarterly*, *26*(2), xiii–xxiii.

Wendler, R. (2012). The maturity of maturity model research : A systematic mapping study. *Information and Software Technology*, *54*(12), 1317–1339. https://doi.org/10.1016/j.infsof.2012.07.007

World Bank. (2021). *Understanding Poverty: Transport*. https://www.worldbank.org/en/topic/transport/overview#1

Yadav, G., Kumar, S., Luthra, S., & Rai, D. P. (2019). Developing a sustainable smart city framework for developing economies : An Indian context. *Sustainable Cities and Society*, *47*(January), 101462. https://doi.org/10.1016/j.scs.2019.101462

Zelewski, S. (2007). Kann Wissenschaftstheorie behilflich fur die Publikationspraxis sein. *Wissenschaftstheoretische Fundierung Und Wissenschaftliche Orientierung Der Wirtschaftsinformatik. Berlin: Gito*, 71–120.

Zhang, M., Zhao, P., & Qiao, S. (2020). Smartness-induced transport inequality : Privacy concern , lacking knowledge of smartphone use and unequal access to transport information. *Transport Policy*, *99*(January), 175–185.

https://doi.org/10.1016/j.tranpol.2020.08.016

Zhao, H. T., Zhao, X., Jian-cheng, L., & Xin, L. yan. (2020). Cellular automata model for Urban Road traffic flow Considering Internet of Vehicles and emergency vehicles. *Journal of Computational Science*, *47*(June 2019), 101221. https://doi.org/10.1016/j.jocs.2020.101221

Appendix

A Interview Guide

Cities around Europe have shown an increased interest in the development of C-ITS projects to become smart cities, and take on transportation challenges. These technologies demand specific expertise and an integrated approach, causing an uneven development between cities in Europe. Consequently, research has been working on disseminating best practices of pilots, and creating city networks to exchange experiences. The goal of this research is to provide an additional tool for cities to evaluate where they stand in implementing C-ITS, how this compares to other cities and identify best practices. This is based on best practices and barriers for decision makers and public authorities that have been identified in literature and during projects for the implementation of C-ITS in urban environments. I developed a maturity model based on these experiences, and am doing interviews with experts to evaluate and ask:

1. Who they are and what their personal experience is with C-ITS projects
2. If they agree with content validity, including the different maturity model dimensions and descriptions, based on their experience.
3. How they assess the problem adequacy of the model, evaluating how useful it is and who the main beneficiaries would be.

Introduction

1. Where do you work and what is your position?
2. Do you have experience with C-ITS projects?
3. Could you tell a bit more about the general situation of C-ITS projects in your city?

Validity evaluation

For the next part, I would like to hear more about your experience on the validity of the developed construct.

1. Are the individual dimensions translated well, could you elaborate on each of the dimensions individually? Is there anything unclear about the different components?

2. In how far do the maturity levels represent a logical evolution path in C-ITS deployment readiness for city authorities?

3. To what degree does the model manage to represent the domain completely? Would you remove any dimensions? Would you add any dimensions, what other processes or indicators determine the maturity of a city for implementing C-ITS?

Relevance evaluation

1. In general, do you believe a maturity model could be useful as an evaluation tool on this topic?

2. Who do you think would benefit from such a model?

3. Would you be likely to employ or recommend a tool like this?

Declaration of Authorship

I hereby declare that, to the best of my knowledge and belief, this Master Thesis titled "Implementing Cooperative Intelligent Transportation Systems: A Maturity Model for Assessing the Readiness of Cities" is my own work. I confirm that each significant contribution to and quotation in this thesis that originates from the work or works of others is indicated by proper use of citation and references.

Lokeren, 09 August 2021

Viktor Simon De Naeyer

Consent Form

for the use of plagiarism detection software to check my thesis

Name: De Naeyer
Given Name: Viktor Simon
Student number: 0796008
Course of Study: Public Sector Innovation and eGovernance
Address: Schlossplatz 2, 48149 Münster
Title of the thesis: Implementing Cooperative Intelligent Transportation Systems: A Maturity Model for Assessing the Readiness of Cities

What is plagiarism? Plagiarism is defined as submitting someone else's work or ideas as your own without a complete indication of the source. It is hereby irrelevant whether the work of others is copied word by word without acknowledgment of the source, text structures (e.g. line of argumentation or outline) are borrowed or texts are translated from a foreign language.

Use of plagiarism detection software. The examination office uses plagiarism software to check each submitted bachelor and master thesis for plagiarism. For that purpose the thesis is electronically forwarded to a software service provider where the software checks for potential matches between the submitted work and work from other sources. For future comparisons with other theses, your thesis will be permanently stored in a database. Only the School of Business and Economics of the University of Münster is allowed to access your stored thesis. The student agrees that his or her thesis may be stored and reproduced only for the purpose of plagiarism assessment. The first examiner of the thesis will be advised on the outcome of the plagiarism assessment.

Sanctions. Each case of plagiarism constitutes an attempt to deceive in terms of the examination regulations and will lead to the thesis being graded as "failed". This will be communicated to the examination office where your case will be documented. In the event of a serious case of deception the examinee can be generally excluded from any further examination. This can lead to the exmatriculation of the student. Even after completion of the examination procedure and graduation from university, plagiarism can result in a withdrawal of the awarded academic degree.

I confirm that I have read and understood the information in this document. I agree to the outlined procedure for plagiarism assessment and potential sanctioning.

Lokeren, 09/08/2021

Viktor Simon De Naeyer