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Towards intelligent public transport systems in Smart Cities; Collaborative decisions to be made

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Abstract

The global context of *cooperative intelligent public transport systems* (C-ITS) in Smart Cities calls for a solution that integrates the perspectives of the travelers, public administration, vehicle manufacturers and transport operators in the joint effort of standardization, interconnection and assimilation of emerging technologies to meet operational, safety and environmental objectives at metropolitan, national or international level. The article proposes a definition for the capabilities maturity levels of the mobility ecosystem, and functional architecture for the collaborative decision-making system for implementing the C-ITS in the future Smart Cities. The paper contributes to the literature and practice in four manners. The first one is enhancing the awareness and understanding of *maturity capability model* (CMM) for all the stakeholders throughout the mobility ecosystem, emphasizing the key capabilities required for each maturity level. The second way is manifested throughout public and private companies acting on the same territory in the mobility ecosystem assess the existing capabilities and collaborate for achieving a superior maturity level of mobility processes, stable and repeatable results. In addition, the third one, based on CMM, is that governments regulate, conduct and control, establishing a stable and mature processes institutionalization for C-ITS. Finally, the fourth practice is defining a C-ITS functional architecture for the future Smart Cities to support collaborative decision-making applied for public transport implementation in big Smart Cities with the final objective of increasing the citizen's quality of life.

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1. Introduction

Over time, since 1980, through public-private partnerships and joint programs, intelligent public transport systems have gone through several stages of evolution, contributing to what we call now C-ITS (Cooperative Intelligent Transport System) [1-5]. However, there are still many cases where C-ITS stops at the border of the

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administered territory or presents incompatibilities within the same territory, in terms of stakeholder collaboration and between similar systems at regional, national, continental or global level.

The improper strategic approaches (e.g. the policies adopted that address only short-term solutions, generate an increase of long-term problems and the lack of institutional collaboration, without coordinated joint actions between different actors or between different transport type), do not allow achieving benefits throughout the mobility value chain. In addition to that, the approaches sustain the unjustified spending of public money, the frustration of all stakeholders in the public transport ecosystem, pollution and accidental deaths.

Changes in the user's interaction with the C-ITS have been slower in the past, e.g. migrating from paper maps to digital systems or replacing the manual issuance of paper tickets with digital payment. The profound technological developments in recent years, such as integrating spatial decision-support systems [6] in all collaborative mobility processes, develop complex analysis engines and AI proliferation over Big Data, with prediction and prescription requirements instead of descriptive and diagnostic analyzes on traditional structured. Future trends stimulate social innovation and improve the traveler's experience in terms of mobility, making possible the emergence of new actors that contribute to creation of the value throughout the life cycle of entire mobility processes and the emergence of new demands of transport services for people and goods [7, 8].

The joint C-ITS's standardization efforts realized by working groups at the local, metropolitan, regional, global level, has been materialized in some cases in locally adopted standards. In another, the standards have been taken from one country and adapted preserving the elements of compatibility and adding local specificity (e.g. Canada [9], which took over and adapted the US standard [10]). Finally, this combined effort led to a set of standards and strategies [11, 12] for the implementation of C-ITS globally, which contributes to the collaborative economy and efficient use of resources in a truly intelligent multimodal transport system.

2. Mobility ecosystem maturity level

Inspired by Carnegie Mellon University, we define the capability maturity matrix for the mobility ecosystem [13] represented in Fig. 1. This definition allows enhancing the awareness and understanding of the capability maturity levels, not only for the government institution but also for all the stakeholders throughout the mobility ecosystem, with the final scope of taking concrete actions on granting strategies and resources for moving forward in addressing the issues of C-ITS. Depending on the common understanding, agreed on priorities and available resources, the movement between lower to higher maturity levels is faster in a collaborative economy, when the government regulates and plans the necessary investment, and provides a stable implementation of C-ITS processes. The lowest maturity level is characterized as primitive, while the higher level becomes a tool that enables collaboration between all mobility ecosystem's stakeholders. The definition of maturity capability emphasizes the transformative roadmap for the countries that have not institutionalized the processes of ecosystem's mobility yet. Turning the perspective, the capabilities for each maturity level become opportunities for C-ITS implementation based on the lesson learned from other best practices experiences (e.g. Canada [8], Japan [3]) and adopt a higher level of maturity capability in partnership. Following the roadmap, the newest emerging technologies become facilitators for accelerating the speed of information flows between all the mobility ecosystem's stakeholders, and are immediately actionable for the entire ecosystem. The decisions about choosing the proper technology have a major impact on the future of intelligent transport systems. The situation is even more complicated because the problem is a multi-criteria and multi-participant one. Besides, the adoption of C-ITS has been potentiated by the pandemic reset and the changes in travelers' habits have smoothed the desire to initiate the adoption of AI. Therefore, the transport control type emerges from the one with drivers to the autonomous type. The new generation of C-ITS meets the requirements of the rapid development of transport by centralizing information, bringing it into the collaborative decision-making system [13-16] as quickly as possible, making available applications and services for public or private companies, suppliers, designers, manufacturers, drivers etc. Beyond the government, the resident people of the city and their behavior influence the C-ITS. In addition, the commuters who live in the area of city influence, and the tourists or transit travelers, keep the cities alive and represent an important share for C-ITS.

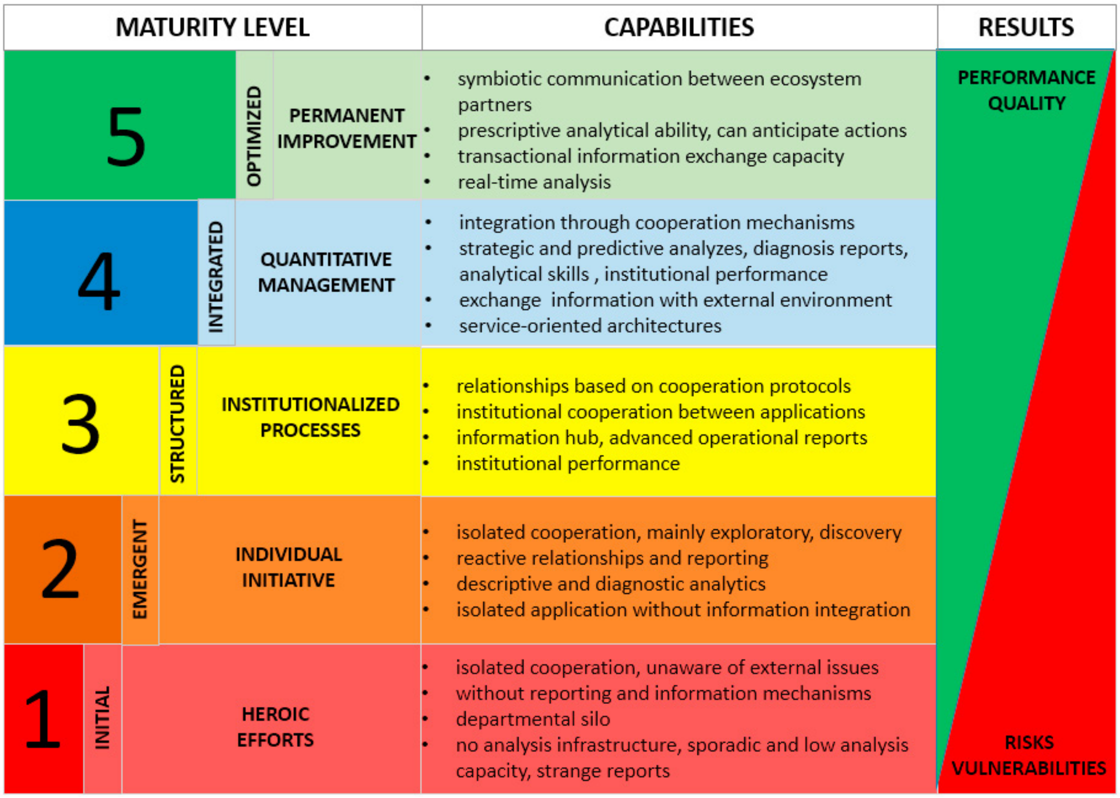

Fig. 1 Mobility ecosystem's maturity levels, specific capabilities and results. Source adapted after Carnegie Mellon University [13]

For a better serving of citizens, we summarize their desires in the following "*cluster*" of ideas: travelling beyond where they could solve current needs, safely, without additional risks and higher costs; reaching a certain planned destination (job, hospital, administrative institutions, events, etc.); travelling simply as a tourist; moving in the idea of discovering new opportunities of any kind; having an interesting, lively and satisfying life, but also perceiving the environment, day or night, sun or rain. Furthermore, being part of the digital transformation, they would have the desire of contacting new people; they would promote a low-impact transport system and respond with the most efficient measures to climate change, reducing the air pollution. The implementation of this *"cluster"* requires the integration of *relevant technologies* organized under the C-ITS technological core.

3. Proposed functional architecture for future mobility

Given the speed of developing emerging technologies, in Fig. 2 we propose a functional architecture for C-ITS towards the future Smart City. Our proposal provides the options for public administration to select the needed functional modules, to define the implementation priorities for needed business functionalities, correlated with the local/metropolitan/national particularities, adapted to the transport travel flows, and supported by the available resources and the availability of stakeholders to share resources in a collaborative economy. Each functional architecture level described below includes three sections inspired by the Canadians [8] architecture:

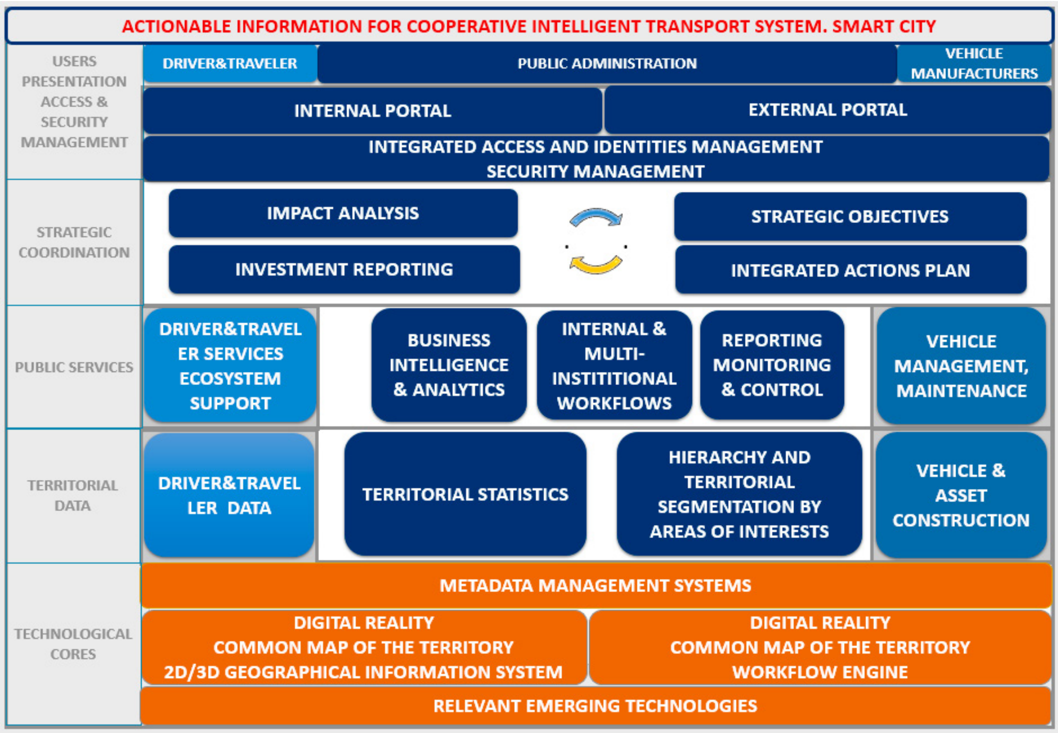

Fig. 2 C-ITS Functional architecture. Source adapted from [17]

- *Technological cores* – include *relevant technologies*, described shortly below, able to support the public services for each ecosystem's stakeholder and metadata management for the data model.
- *Territorial data* – include statistical data and hierarchical infrastructure (physical and logical) data model aggregated in a common territorial map and shared within mobility ecosystem's stakeholders. The most important data types related to driver & traveler are social media, crowdsourcing and notifications/proposals, complaints. The basic maps (landscape, *LIDAR*, mosaic of satellite or orto photogrammetric images, transport and utility infrastructures, *Automatic Vehicle Location (AVL)*, parking, pollution measurements, weather alerts, active work permits, CCTV and IoT sensors, traffic safety, demography, entertainment, business advertisers content, and any other type of open data are just a few of the categories managed by public administration. Vehicle manufacturers share IoT for vehicle and assets.
- *Public services* – are personalized services for each stakeholder category, based on internal & multi-institutional workflows. For the internal business public administration's workflows support it is provided, such as planning and design investments, transport licensing, fleet management, depot and platform management, smart ticketing payment, safety management (traveler, vehicle, and station), video management, analytical engines and AI [2], alerts, reporting, monitoring and control. For the drivers and travelers, the services include remote personalized user support, parking information and routes, touristic resources, electronic payment, personalized content, access to personalized content, advertiser add-on and more other based on market offer request and emerging technologies development. The vehicle management services become available for the manufacturer.

- *Strategic coordination* – includes a module that manages the common objectives, the integrated action plan, the correlated investments between all stakeholders and the impact analysis of their actions.
- *User presentation. Access & Security management* – uses digital user identity for accessing the internal and external portal based on roles and visualization tools designed for web and/or mobile.

The geospatial technologies deliver superior situational awareness by collaborative decision-making. Mobility as a service and mobility on demand become features for the proposed solution.

The proposed C-ITS for the future Smart Cities is based on a *seamless intermodal journey*, *in-vehicle transit experience, in-vehicle services, shared autonomous vehicle* [8], dedicated transport network and properly equipped (own lanes, transponders, intelligent traffic lights, etc.).

Based on advanced AI and data analytics engines [2], the transport planning is automatically re-dimensioned taking into account the impactors and constraints (e.g. accidents, traffic jams, previous user pattern transport requests and services used). Thus allows booking a place or knowing the arrival times. Simulations before the trip are common functionality, performed and confirmed. The subscription decrease with a quantified for the unpaid trip, rising the responsibility for the use of transport infrastructure. The transport demand determined in the above way allows the dimensioning of the used transport fleet based on different types of vehicles of different capacities (places) on routes according to demand. The autonomy brings means of transportation without the involvement of the human factor in driving, allow the efficient use of vehicles (eliminating the necessary rest times for drivers after each race, lunch break, medical leave, leave, etc.). In our proposal, the main element for the Intelligent Transport System becomes the *Intelligent Boarding/Unloading Station*. Within a radius of 300 meters around the points generating displacements (housing, jobs, various objectives, etc.) such stations are located to ensure network access for each user. The access to transport services is secured (by glass gates operated by sensors or devices) both at the entrance of the station and when boarding the vehicle. Autonomous vehicles stop at a fixed point. The "station" recognizes the traveler and provides access based on user digital identity for the user registered in the platform, or just based on the presence of mobile devices attached to the traveler. By enrolling a virtual card/account (based on cryptocurrency) the user can purchase personalized transport services, subscriptions, additional information, recommendations for using the transport network at advantageous costs, etc. There are also situations in which the intelligent transport system recommends travelers to use the transport network between certain hours, outside peak hours. Another option is dynamic changes of transport direction depending on the network load on-peak hours. An important aspect of the proposed solution is that services and applications become available for all consumers type by roles and access rights.

In the following section, we emphasize the *relevant technologies* for implementing C-ITS:

- *5G technology* and *6G technology* , the last one estimated for 2030 [18], with increased capacity (up to GB/s respectively TB/s) and reliability, faster processing, increased mobility, low latency and high-energy efficiency, according to the new EU strategies [12], facilitating the AI-based operations, autonomous vehicle communications, V2X (vehicle-to-anything, such as other vehicles, infrastructure smart devices, pedestrian, server applications, services [26]) and a higher level of user experience with multisensory communications, accelerating the emergence of 6G;

- *Big data, Cloud Computing [2, 19]*, large distributed volumes of data and data analytics services without the need for knowing the location and physical configuration of these services;

- *Artificial Intelligence* (AI) *and Analysis engine* [2], used for supporting the proactive decision-making to be taken in a shorter time; includes descriptive, diagnostic, predictive and prescriptive analytics and AI or *intelligence* exposed by cars, which contribute to autonomous transport;

- *IoT (Internet of Things) [20],* improve situational awareness both for vehicles and the driver by integrating IoT with spatial location, and with 5G; pushing vehicle network performance for traveler personalized services: IoV (Internet-of-Vehicles), V2X (Vehicle-to-anything, vehicle to vehicle, smart devices infrastructure, pedestrian, server applications, services [26]);

- *The AV (Autonomous Vehicle) and the CAV (Connected and Autonomous Vehicle)[2, 21]*, are capable of feeling the environment and moving safely with little to no human intervention, communicate with each other or with road items (V2V, V2bicyclist, V2pedestrian, V2home, V2grid, V2infrastructure); technologies like GPS, lidar, radar, laser, computer vision, radio to avoid collisions, help safety and improve traffic flow. Based on LIDAR [22] is provided 3D secured information for high-precision monitoring and analysis (classification of moving objects, measuring speed and position of vehicles and pedestrians, identifying motorized or pedestrian traffic flows patterns, identify obstacles, identify pollution) and enhance traveler experience and entertainment, safety, comfort;

- *Digital twins* [23] are digital models of the physical world able to ingest constant updates and made possible transport network simulations and analyses for problem understanding, testing the proposed solutions for traffic optimizations, integrated with other components like AI and analytics engines, aggregating information from road IoT infrastructure or traffic and GIS spatial analysis;

- *BIM (Building Information Modeling)[24]* is the data model of infrastructures of any kind, including transport and construction that can be interrogated in different autonomous vehicle user scenarios;

- *The Electric Bus, Hydrogen Fuel Cells [25]* is fueling solutions for future mobility, compatible with the EU's climate neutrality target;

- *Cybersecurity [2]* is critical hardware and software for intelligent transport that provides high-infrastructure security;

- *GIS Spatial analysis* [6] is the framework that allows the collection, management and analysis of spatial data support for planning and monitoring intelligent transport;

- *Social media [2],* facilitating passive crowdsourcing-type data posted online by travelers on social networks (different social applications - Facebook, Twitter, LinkedIn, Instagram, WhatsApp and other), blogs or online video platform – YouTube analyzed related with the location for traffic predictions, incidents, accidents. Another data category uploaded by the traveler in free mobile applications, such as Waze, Google, is used for deducing the slowdown in traffic and to identify the potential traffic situation;

- *Global standardization (ISO, CEN, ETSI), recommendation (ITU) and specifications (SAE) for C-ITS [11],* allowing the local, metropolitan or national and international integration between different intelligent transport systems.

The proposed functional architecture offers the public administration the chance to decide a framework for collaboration unlocking public transport services via clouds, using all benefits provided by the next generation of mobile connectivity, 5G, the secure connectivity with low latency and high bandwidth. Acquiring these capabilities and institutionalizing the mobility processes, newly developed public transport services will emerge in Smart City aligned with global standards and providing a guide for C-ITS implementation with benefits for all mobility ecosystem's stakeholders and contribute for improving the quality of life.

4. Conclusion

The proposed architecture for C-ITS unlock the data and provide new user experiences expanding services and collaboration between participants/actants to the ecosystems' mobility. Only understanding the requirement for capabilities and developing the highest level of maturity for C-ITS at the institutional level, it allows improving mobility - reducing traffic congestion by public transport optimization in Smart City, reducing carbon emission, increasing safety by reducing the number of accidents. Following this approach, C-ITS becomes operational, effective, proactive resilient in real-world (stress) conditions, fully autonomous and collaborative decision making by machines, using predictions, forecasts, simulations, rules, optimization, AI, auto-adaptive and resizable in real-time based on load monitoring or passenger requests. Risks are managed by guardrails or by human-in-the-loop for exceptional cases.

The C-ITS functional architecture framework could be adopted by Smart Cities and continuously updated with the global standards [9] and it would provide a proper answer to the pressure of the single EU market. Implementing government policies, regulations and procedures, developing knowledge and expertise in each country develop interconnection mobility C-ITS across the entire country and between countries, avoiding future integration costs and capitalizing on ongoing funding opportunities (European or other available), all this open widely the public transport to the future Smart Cities.

Future research aims to deepen the global existing architectures adapted to emerging technologies. A detailed analysis of the required services will be performed either for their development or for the upgrade to the new version of the C-ITS.

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