Evolution paths of stakeholder-oriented smart transportation systems based on 5G

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Abstract

Societies are experiencing large-scale transformation through digitalization programs covering all private and public sectors. Digitalization advances also the growing demands of sustainable development, in which nations and cities all over the world have set ambitious targets. Transportation is one the cornerstone verticals of cities and has attracted wide attention from various stakeholders developing services and solutions for digitalization. In general, ICT solutions are in the core of digitalization and trailblazing technologies have been developed to enable modern transportation services. 5G technology covering wireless connectivity, IoT sensor technology, distributed edge computing, artificial intelligence, high power computing and service platforms offers numerous opportunities to the development of sophisticated smart transportation services. However, to adopt a pervasive approach for the evolvement of digital transportation services, it is important to examine the system level point of view. Developing occasional services for various transport modes without targeted inter-operability of services, the result of digitalization of transportation can be extremely fragmented. This paper aims to highlight the top-down angle of research and development of the smart transportation system. The development requires seamless co-operation of researchers and specialists of transport systems, urban design and planning and wireless technologies to integrate transport infrastructure, 5G wireless communication infrastructure and traffic management systems to enable advanced digital services for all transport modes. Moreover, this article introduces the stakeholders recognized from transport systems, urban design and planning and wireless technologies. The role of each stakeholder is described a like.

1. Introduction

Transportation is under a strong subversion. Sustainability targets set new requirements on the development of future transportation systems and can be solved partly by digitalization. When aiming at lower carbon emissions, improved management systems, and introduction of new transportation modes and services, digital information and communication technologies (ICTs) plays a key role in accelerating the disruption of transportation. Research projects have already developed multidisciplinary and holistic approaches to Smart City transportation system evolution (Andrisano, et.al., 2018). The future transportation systems not only cover a variety of moving vehicles, machines or drones that necessitate the use of wireless technologies but also services in different transportation categories. For a widespread adoption of ICT solutions into future transportation, wireless 5G networks and their evolutions will need to be integrated with the actual traffic infrastructure development and operation, which is typically under the control of municipal governance and urban design and planning (Toh, et. Al., 2020; Mădălin-Dorin, et.al., 2017).

It is obvious that the disruption of the transport sector will be largely based on digitalization and wide adoption of ICT technology. Many pioneering sectors like industry, health and logistics have made successful pilots of digital transform by trialing 5G technology. Several digitalization projects are running in the transport sector. Typically, the pilots cover a particular section of the transport vertical e.g., autonomous vehicles, road maintenance, drone services or public transport services, but a systematic approach of the transport sector development is usually missing in the digital transform pilots and articles. This study emphasizes the significance of adopting a holistic view in the development of digital future transport system assisted by 5G technology. To determine the view, it assumes to identify the stakeholders and to compose the requirements of the transport system. Subsequently, this results in the specification of the system requirements and preparation of digital transport roadmap before taking the concrete steps forward.

This paper aims to seek novel approaches to digital transportation system development in Smart Cities, taking advantage of latest 5G networks and their evolutions. As the digitalization of transportation is largely based on ICT innovations in several research areas such as wireless communications, sensors, edge and cloud computing, and AI technology, multidiscipline co-operation is needed to include holistic system level development and aspects of urban design and planning processes (Andrisano, et.al., 2018). A research project at the University of Oulu in Finland has involved researchers from wireless, computing, environment, transportation, architecture and business research groups as well as developers from the city office. The outcome of the common contribution has resulted to suggest evolution paths of processes to develop digital transportation system assisted by 5G technology, which are discussed in this paper. This is composed of several sub-areas, which are categorized in the following development areas: 1) digital transportation system, 2) processes of urban design and planning, and 3) ICT infrastructure.

Transport systems and urban design and planning are interlinked, and their plans should be drawn up in parallel processes. Consequently, the digitalization of transportation in Smart City context (see Figure 1) cannot be done outside of urban design planning and its processes. Smart City approach will have an impact on the objectives of the plans and expected outcomes of the processes (Fernandez-Anez, et.al.,2018). The city planning authorities execute participatory urban design and planning processes with wide range of stakeholders (Freeman, et.al., 2010) such as decision-makers, residents, authorities, public and private services, NGOs, organizations, companies etc., who apparently have different expectations for the digital transportation systems.

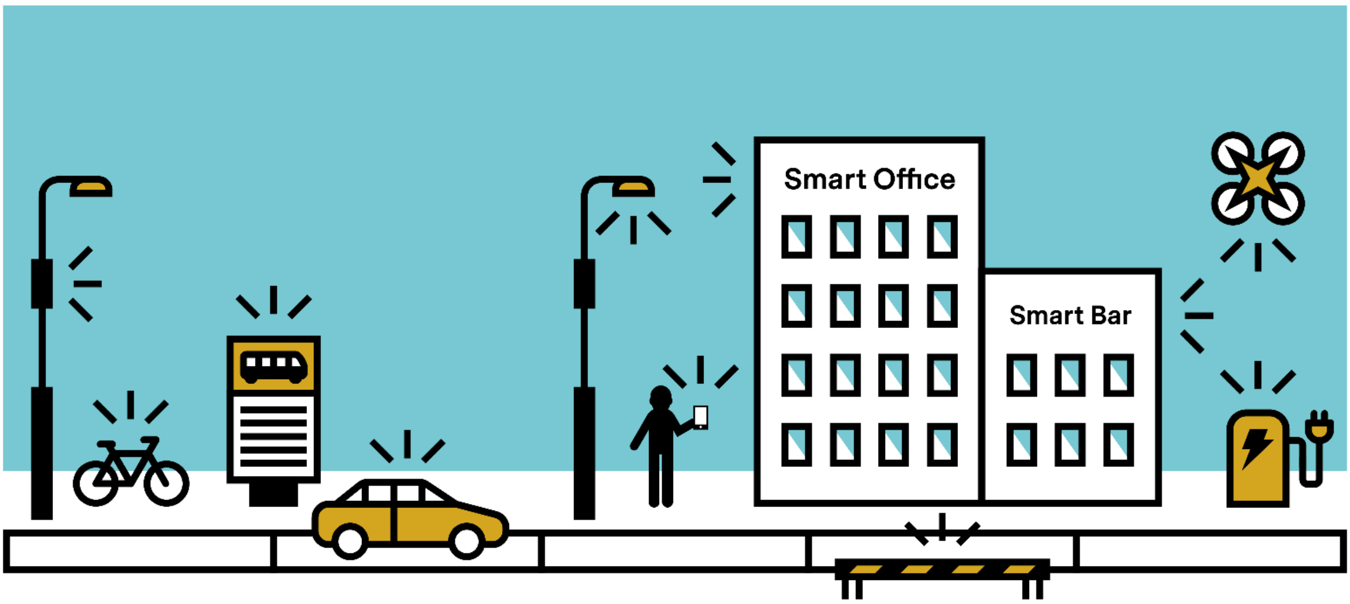

Figure 1. Vision of digital transportation system of Smart City

The transport system here is first defined as a system comprising transport infrastructure, different modes of passenger and freight transport, and traffic management systems. In addition, an important part of the transport system of the future are the mobility services and real-time information, which, together with the infrastructure, should form an interoperable entity (Neilson, et.al, 2019). The development of future transport systems of smart cities is influenced by urban city planning developments as well as the ICT developments, where the role of 5G and its evolutions are important as they support mobility. These aspects lead to the following research question:

1) Who are the key stakeholders and what are their requirements to develop the Smart City transportation systems?

Regarding infrastructure, the utilization of 5G and beyond technology can be an integral part of future transport system development. Various vehicles like autonomous cars, maintenance vehicles and flying drones generate high amounts of data, which is required to be wirelessly transferred with high speed and low latency. The transport systems of cities will be probably crowded with IoT sensors to produce environmental data, which is assumed to be shared in real-time for different traffic services. The 5G technology and its evolution offers e.g. high-speed wireless data transfer, edge computing, analytics and artificial intelligence for these purposes. This raises the second research question:

2) What capabilities can 5G infrastructure offer to future smart transportation system development?

Smart transportation system developments call for bringing together the transportation system requirements, urban design and planning processes and infrastructure development. This calls for a specific process which includes the key stakeholders to define the development path model for the smart transportation system. This leads to the third research question:

3) What are the scenarios of developing future smart transportation systems, when reflecting to the development of future wireless communication technology and processes of land use planning?

This article has been structured followingly. Chapter 1 presents the research topic and introduces the research questions related to the development of smart transportation system. Chapters 2, 3, 4 discuss about the status, processes, methods and characteristics of factors of smart transportation system introducing background of transportation system, urban design and planning and 5G technology. In the chapter 5. there have been presented the scenarios of expected evolvement of the digitalisation of transportation system. The Chapter 6. introduces the actual stakeholders and their roles in the development. Additionally, there is a table to compose the expected contribution level of each stakeholder. In the Chapter 7, there are conclusions and recommendations to develop digital smart transportation system.

2. Background on Smart transportation system

Transport sector is facing big challenges driven by the impact of climate change, urbanization, aging population, and a shift in people's attitudes and lifestyles. Climate change is tackled mainly by favoring sustainable modes of transport and switching to low-emission technologies (mainly electrification) and fuels, which affects traffic composition and flow, fuel distribution infrastructure and the operation of the transport system (Ministry of Transport and Communications, 2018). The changes in age structure and people's behavior place new requirements on the transport environment too. For older people, certain features of the transport system, such as accessibility, affordability, reliability, convenience, safety, and security are particularly important (Johnsona, et. al., 2017). On the other hand, younger generations have a different attitude to personal mobility than their parents; for example, they do not necessarily intend to obtain a driving license and consider owning a car. Instead, they prefer new transport services, such as car sharing, ride hailing and Mobility as a Service (MaaS) solutions (and have more positive attitude to self-driving technologies /automated driving). E-commerce is also rapidly increasing its popularity, adding to the demand for development on city logistics. In addition, migration to cities will further stretch existing systems functionality and fluency as demand rises.

Digitalization is assumed to be one of the ways to solve these challenges and remains strong on national agendas all over the world. In the field of transportation, the term digitalization relays widely on the concept of Intelligent Transportation Systems (ITS), which is defined in the directive of the European Union (Directive 2010/40/EU) as modern applications of information and communication technologies providing services related to different modes of transport and transport management, which enable users to be better informed and make the use of transport networks more coordinated, safer and smarter. With digitalisation, large amounts of data are collected from different users and locations in the transportation system, and after processing that knowledge is exploited elsewhere. The connectivity created by real-time communication opportunities is a key factor of the future transportation system.

Sustainability, efficiency, and safety are established characteristics of the transportation system, only their weightings have changed over the years (Ministry of Transport and Communications, 2013). With the servitization of the mobility, the customer focus and convenience of use have emerged as important features. Digitalization makes it possible to influence all of these qualities expected from the smart transportation system of the future. Digital applications and solutions allow to reduce risk situations and accidents, congestion, CO2 emissions and other harms caused by transport and, on the other hand, increase traffic fluency, accessibility, reliability and comfort. In addition, digitalization enables the use of existing infrastructure and supply chains to become more efficient and supports the introduction of new transport modes and services.

Digitalization affects all modes of transport and parts of the transportation system. For instance, in order to promote sustainable modes of transport, information systems have been implemented for walkers and cyclists, consisting of calculation and display points installed across the city to inform road users about traffic volumes. Information on air quality may also have been linked to these information points. Again, efforts are being made to increase the amount of winter cycling by providing cyclists with real-time information about the movement of snow plough and the condition of bike paths, making route choice easier.

The popularity of public transport can also be influenced by smart solutions, such as journey planning applications and electronic tickets. There are mobile apps available in many urban areas that allow people to plan their trips, buy tickets and get up-to-date information, e.g. scheduling changes. A number of different modes of transport, such as bus, subway, and urban bicycles, can often be used with the same ticket product. There are also a few MaaS solutions in the market that combine different transport options from different providers, both public and private. Customers can easily access the entire travel chain, with a range of travel modes, through a single mobile app. In addition, a lot of different solutions based on the sharing economy are already available, for example car rental services from local people and taxi-sharing service.

The most stringent requirements for transportation system data transmission and processing are caused by the development of automated and connected driving. During the last decade or so the visions have progressed into real technological achievements and enabled the development of prototypes of autonomous vehicles (AVs) (Faisal et. al., 2019), accompanied by massive testing and piloting around the world (Bloomberg.org Group, 2019). Only a few automotive manufacturers have been developing and testing fully autonomous vehicles with sensor-based systems that rely solely on sensor data (Singh, Nandi & Nandi, 2019), while many others believe connectivity is necessary in safe and efficient autonomous driving (Machardy, et. al., 2018). Communication with other vehicles, surrounding infrastructure and pedestrians is intended to inform the vehicle timely about oncoming traffic situations and to assist in decision-making (3GPP TR 36.885, 2016). As the latest generation of mobile communication technology, 5G is expected to reach improved levels of latency, efficiency and connection density and is already piloted for automotive applications (Hetzer, et. al., 2019; Keysight Technologies, 2018; Kwoczek, 2015).

For smooth mobility and the whole transportation system to work well together, traffic management needs to evolve as well. The future transport system will be even more complex than it is today, resulting in demands for digital information, related to static physical and digital infrastructure, traffic situation, and surrounding conditions, and structures and ecosystems to make the necessary information move between different parties . Already now a large amount of data is available from transportation system, but not all of it can be used to its full advantage. In order to comprehensively manage the transport system, an integrated information system is needed to gather and process real-time information from multiple sources and provide a real-time situation picture of the transportation system. That kind of system would allow real-time information sharing and management of different modes of transport, help alleviating congestion and responding to unexpected situations, such as accidents. One example of such a traffic management center is the “Control Tower” for Seoul’s Intelligent Transportation System (TOPIS) which has being developed from the beginning of 21st century. Moreover, most of the infrastructure does not yet support future mobility changes. When developing new technologies, the requirements for infrastructure that facilitate them are often ignored (Lotz, 2019). Automation, for example, will have a major impact not only on the digital infrastructure but also on the physical transportation environment. It is assumed that long-term changes to infrastructure may include, e.g., own lanes or other parts of the infrastructure for different groups of traffic users, on-street drop-off and pickup areas, yielding areas, and landing sites for drones (Traficom, 2020). The challenge is that a common view of the requirements of equipping infrastructure is lacking. To solve this problem multi-disciplinary approaches are necessary.

3. Background on urban design and planning

The development of future transportation systems needs to take into account land use planning that defines the regional structure and community structure and involves stakeholders in the processes. Land use planning is a process where conflicting interest are managed in *statutory* and *participatory* process. The stakeholders participate in preparing the plan, estimate its impact and state their opinion on the plan. They may also set targets for the process (bottom-up approach). Land use planning is also a political process since regional and local authorities and political bodies use their mandate to set targets, approve the contents of the plans and make decisions based on the land use plans. The land use planning system is *hierarchical* progressing from more general to more detailed: a more general plan shall be used as a guideline in drawing up and amending a more detailed plan. This procedure will ensure the development of regional and urban structure in a consistent way. The results of the statutory urban design and planning processes must be presented on maps; the legally binding regulations and plan symbols either enable or restrict activities. Land use plans must be taken into account in designing roads, railroads, streets, and buildings, since the projects must be in keeping with the valid plan.

As mentioned earlier, transport sector is facing big challenges. Similarly, complex issues such as urbanizations and shrinkage, changes in labor and trade, ageing, multilocation,smart traffic, circular economy, resilience, climate change etc. should be tackled in urban design and planning context. Contemporary land use planning manages transportation issues as follows:

1) National transportation systems are connected to international networks such as The Trans-European Transport Network (TEN-T) (European Commission 2021). Since local and regional land use plans must be in line with national and international development, the state has an interest and authority to set objectives for planning in general. *The revised Finnish Government Decision on National Land Use Guidelines*, which is situated at the top of the Finnish national land use planning hierarchy even if compiled in a text format, focuses on 1) functioning communities and sustainable traffic, 2) efficient transport systems, 3) healthy and safe environment, 4) viable natural and cultural environment and natural resources and 5) energy supply capable of renewal. Accordingly, transport system is a key factor in low- carbon society, and digitalization and automation enable intermodal travel and transport chains [Finnish Government 2017)

2) The national road network is designated in *regional plans* drawn up by regional councils, since the regional council must especially carry out regional planning (Land Use and Building Act 132/1999 19 §). The regional council must ensure that the regional transport system is designed in accordance with the principles in national transport system (The Act on Regional Development and the Administration of Structural Funds 7/2014 17.1§. According to government proposal (45/2018) smart traffic solutions, digitalization and automation should be assessed and implemented in designing the regional transport systems.

3) *Municipal* land use planning is targeted to solve planning issues in municipality's territory. Municipalities have a land use planning monopoly and therefore the local authorities are obliged to take charge of land use planning in their territory (Land Use and Building Act 132/1999 20 §) i.e. to draw up local master plans and local detailed plans. Since international and national interests are implemented in regional plans, the regional plan will give guidelines to local master plans (Land Use and Building Act 132/1999 54.4 §). *Local master plan* will provide general guidance regarding the community structure and land use of a municipality or a part thereof, and to integrate functions (Land Use and Building Act 132/1999 35 §). Defining local transport systems and locations for road networks is a fundamental part of local master planning. Municipalities together with road authorities designate the road network, indicate different types of roads and their location in the region and in the municipality. Strategic objectives can be implemented in local master plans due to its general approach and the idea of presenting the principles of targeted development. *Local detailed plans* are targeted to create the preconditions for a healthy, safe and pleasant living environment, locally available services and the organization of traffic (Land Use and Building Act 132/1999 54.2 §). Public areas such as

parks, market areas, street areas and traffic areas are designated in the local detailed plans (Land Use and Building Act 132/1999 83 §) and therefore the decisions made in the local detailed plans define the structure as well as the space syntax of the built environment.

The contemporary land use planning process aims at integration of the *existing* modes of transportation and acknowledged functions in urban structure as follows:

i) By making the transportation networks visible on maps, i.e. airports, harbors, highways, streets, pedestrian, and bicycle roads etc.

ii) By designing urban structure which will reinforce the presumed mobility behavior i.e. infill development along the railways, sufficient density rate for the public transportation, sufficient space for pedestrians and bicycles, accessible commercial and public services etc.

iii) By integrating multidiscipline and participatory approach in planning procedures to increase mutual understanding and shared knowledge.

iv) By integrating land use planning and transportation planning in *strategies* and development programs such as Mato (City of Oulu 2020), KymppiR (City of Jyväskylä 2021) and Agreements concerning land use, housing and transport (Monistry of Environment 2021).

In an increasing extent urban structure is organized and identified by *urban fabrics* (Newman et al. 2016), *urban zones* (Ristimäki et al. 2007; Ristimäki et al. 2013; Ristimäki et al. 2017) *and Travel Time Budget (TTB) i.e.,1 hour time budget (*Ashmed and Sopher 2014)

According to Newman, Kosonen and Kenworthy (2016) *Three Urban Fabrics (TUF*) consist of walking city, transit city and automobile city. The optimal radius for Walking Urban Fabric is 0-2 kms (core 0-1 km), for Transit Urban Fabric is 0-20 kms (inner area 0-10 kms), and for Automobile Urban Fabric is 0-40 km. The zones may overlap but each zone should be designed according to preferable Fabric Elements. In Urban Fabrics (UF) approach attention is paid at the traffic to and from the *downtown area*. Accordingly, UF approach is based on the classical urban structure and hierarchy.

The Theory of Urban Fabrics has been background for advanced planning methods. In research projects Urban Zone 1, Urban Zone 2 and Urban zone 3 (Ristimäki et al. 2007; Ristimäki et al. 2013; Ristimäki et al. 2017). *Urban Fabrics* were transformed to *Urban Zones*. The favorable transport modes were analyzed using GIS-based analysis of transport system and built environment. As a result of these projects urban zones and subzones are identified and displayed on a statistical grid of 250 x 250 meters, utilized in the Finnish Monitoring System of Urban Form and Spatial Structure (MUFSS) (Ristimäki et al. 2007). These zones will be implemented in regional and municipal urban design and planning projects as input or/and assessment data. The development of urbanization and urban sprawl can and will be analyzed in Urban Zone context by the ministries, regional and local authorities. Urban Zones (UZ) will have an impact on urban design and planning processes accordingly. Transport system planning and urban design and planning are fused and hence this interconnection will, inevitably, modify the way we design our built environment. In UZ approach the transport modes and their space requirements can be identified and regulated. UZ approach presumes stability and adaptability. The aim is that the traveler will adapt his /hers travel behavior feasible for UZ in question.

Travel Time Budget (TTB) is time budget, which a person is willing to allocate for travels per day. It is not an exact and measurable unit. In general, TTB is expected to be about 60 minutes and the budget seems to be identical globally and in different eras of history. Travel Time Expenditure (TTE) is measurable and exact (Ahmed and Sopher 2014) but in this paper we will focus at TTB, since it will impact on the design objectives and anticipated behavior of stakeholders in planning process. According to Ahmed and Sopher multiday, multiperiod, inter-individual and intra-individual aspects should be taken into account in conclusions about TTB in general. TTB should also include analysis of all transport modes, not only motorized. Several factors such as age, gender, car ownership and income may give mixed results. Factors like employment and household size, on the other hand, will show constancy. Bio-physical and biological factors may impact on individual's travel choices, if energy consumption used for daily travels exceed the optimal level. (Ahmed and Sopher 2014) In TTB approach individual decides on transport modes which fits in the TTB. According to Ahmed and Sopher "TTB has important policy implications for urban transport. If TTEs remain below the TTB, then people may expend additional time on travelling. The margin between TTB and TTE has implications on changing route, retiming journeys, choosing a new destination for the same purpose, increasing travel frequency, and making new trips." TTB is a *traveler-oriented* approach and hence stakeholder's personal ambitions play important role in travel behavior.

Contemporary planning, as described in this text, acknowledge traditional transport modes and traditional urban planning procedures. In Urban Zone approach the focus is at enforcing the use of favorable transport modes in urban environment, which embodies the physical qualities defined for each Urban Zone. In Travel Time Budget approach, the focus is at limited source of time. As a conclusion, we will actively design our built environment to correlate/ resonate our comprehension of favorable transport environment. Urban planners are confused by the recent development since the recognized and enduring planning objectives are constantly changing. What are the transport modes in smart traffic context and what kind of built environment will challenge and urge to use the smart transport modes? What kind of urban design and planning is needed to support digitalization, MaaS, 5G-based transportation system?

4. Background on 5G technology

It is evident, that the transport infrastructure and digital infrastructure will be merged and a top-down approach with clearly defined roadmap need to determined and digital transform programs are required to be initiated accordingly to develop smart transportation system (Traficom, 2020.). 5G and beyond technology will probably give many answers in the discussion of future transport system, but it needs to be tailored specifically for the transport vertical, which assumingly brings particular requirements in terms of high amounts of data, low latency and continuous connectivity. The requirements raise from the needs like mobility, alternating environments and real-time information of the system. The 5G and beyond technology can be used to continuously produce updated situation awareness of the transport system.

Common agenda for many verticals in the digital transformation is collection, refinement and utilization of data, which applies also in the transportation vertical. To develop sophisticated 5G technology-based services for transportation, vast amounts of data need to be collected from various sources. The data sources can be in the immediate surroundings, where the data is consumed, or the data can be collected from other locations, circumstances and verticals. This means that a dedicated infrastructure is needed for data collection including 5G network systems with static and mobile IoT sensor systems integrated in transport infrastructure, city furniture, vehicles, drones and maintenance machines. (Knieps 2019) Another potential source of data is crowdsourcing by users with smart phones and various mobile terminals. Data collected by users enable to generate frequently updated data from environments and things, which could be otherwise left out. 5G technology provides the means for efficient and safe data management process from collecting of data to sharing of data. 5G together with IoT technology cover wireless transfer of sensor data, distributed edge computing for local data processing and sharing, centralized cloud computing capabilities for data refinement and integration. Moreover, advanced algorithms and artificial intelligence technologies are used to recognize e.g. environmental phenomena and user patterns, which enable to develop personalized services for passengers.

The 5G technology offers several characteristics, which can be adopted in the development of smart transport system. Attributes like ultra-high-speed wireless data transfer, powerful handling of data, very low latency and massive machine-to-machine communication enable to develop unforeseen services for passengers and transfer of goods (Al-Falahy et.al., 2017). Future vehicles like autonomous cars, maintenance machines and service drones will generate high amounts of data, which require powerful handling and refinement to enable future transport services (Chaqfeh et.al., 2016). Assuming, that various vehicles, machines and robots will generate vast amounts of data, it is essential that the data is transferred to computers capable to process the data in short time. Subsequently, one of the key capabilities of 5G technology is edge computing meaning that high amounts of data can be processed powerfully very close to users instead of transferring data to distant data centers for computing processes. The edge computing shortens the network delays i.e. enables low latency to receive quick response back to the user from the network. In the past a typical latency times have been tens of milliseconds, while with the 5G technology less than 10 milliseconds can be achieved.

5G technology supports also massive machine-to-machine communication, which assumingly has high importance in the future smart transport system, where there are numerous sensors, devices and machines connected in the 5G infrastructure. The system enables machines to communicate with each other without human intervention, which probably improves the system performance and increases reliability of the system. In the transport domain numerous cases can be recognized, where the above mentioned 5G characteristics are a great benefit allowing to develop future digital services. To give examples, an autonomous car may require response from the network in tens of milliseconds to be able to make decisions for safe driving. Another example is, that a maintenance vehicle may generate data from road condition, which need to be transferred urgently for repair actions. Or, a drone which is collecting data around the city can deliver real-time video or data from special circumstances like accidents, traffic jams or fires. The 5G network deployments will be mostly conducted in densely populated areas like city centers at the first phase. Similarly, the digital transportation developments will be first executed in city areas, where the requirements to transportation system and need of new services are the highest. To harness the best characteristics of 5G and IoT technologies and to develop enhanced real-time data-based digital transport services it assumed that the 5G network deployment is very dense at the city centers. For cost-efficient and flexible deployment of 5G networks it will be a benefit if the existing infrastructure like lamp posts, traffic lights or traffic guides in city centers can be utilized (Di Vito et.al., 2020).

However, as the previous network technology generations from 2G to 4G, also 5G has been developed with a strong engineering focus. This means concentrating on particular characteristics, which are e.g. ultra-high data rate, extremely low latency, massive M2M communication and low energy consumption in 5G. Even if these are magnificent features compared to earlier generations, they are not developed from consumer of from professional vertical user perspectives. Instead of engineering approach, various verticals like transportation, health or real estate sector would probably have separate views about their needs for connectivity, data management and data-based services. Furthermore, the current deployment of 5G networks follows strongly traditional models of frequency licensing, where national mobile network operators (MNO) are granted the whole frequency spectrum. The MNOs build the networks with established business models based on the 4G network topology, which can be too sparse for the 5G technology. This can result in situations, where the novelties of 5G technology cannot be fully utilized due to weak signal propagation in city environments. Instead, the 5G networks should have denser grid outdoors and increasingly more indoor networks would be needed. It is prominent that with the 5G technology there appears new opportunities to deploy local networks and private networks by new entrants (Benseny et.al., 2019, Ahokangas, et.al, 2018). It is foreseen that the 5G era of 2020's will be spent with the transition of telecom market, and we will see real end-user-oriented and vertical-based networks only in the era of 6G technology in 2030's. The ongoing 6G research is highlighting human-centered technology development and focusing on selected verticals like industry, health and transportation (Latva-aho & Leppänen (eds.), 2019).

5. Developed Scenarios

Canvassing the ongoing development and predictable disruption of the transport sector's big developments are ongoing at present. Massive investments are being done to ramp-up the electric vehicle transportation by the car industry, electronics industry, software industry, infrastructure stakeholders and other service providers (Lee & Clark, 2018). Accelerating the market sets high demands to the usage of nature resources, production and delivery of energy and recycling of materials, which all need to be solved (Hall & Lutsey, 2018). In parallel, all the transport modes are heavily developing new services to offer alternatives to consumers with strong awareness of sustainable lifestyles (Neilson et.al., 2019).

There are still many open questions like future fueling of vehicles i.e. is it electric, hydrogen gas or all of those depending on emissions, location and personal needs of transportation. In case of electric cars, the charging infrastructure must be available also in suburban and rural areas. Another question is the development of autonomous vehicles, if they would they solve some major problems of transportation by V2X communication between vehicles and between vehicles and infrastructure. Subsequently, aerial transportation will be probably in significant role with the employment of service platforms of flying drones to solve challenges of logistics in future cities. Active discussion is ongoing about electric planes, which could reach suitable range to operate between neighboring and domestic cities at the first phase (IATA, 2020). Numerous commercial pilots will be conducted when developing digitalization and data-based services for all modes of transportation. The most potential pilots will probably remain to be developed further. However, piloting and deployment of discrete digital services does not support top-down approach of developing integrated smart transportation system. The aim of urban design and planning is to "ensure that the use of land and water areas and building activities on them create preconditions for a favourable living environment and promote ecologically, economically, socially and culturally sustainable development" (Land Use and Building Act 132/19991§). Accordingly, when planning digitalization and 5G based transportation, we will also affect individual's traffic behaviour. By active incentives we may change the existing modal share distribution. The modal split varies locally depending on 1) the physical structure (geography), 2) the age and gender distribution and 3) on the local transportation policy. Traficom's research on the impact of sustainable mobility measures on the modal split (Auvinen et al. 2020) identifies four central stakeholder groups: 1) public agencies (state), 2) business sector (market), 3) communities (households, families) and 4) non-profit (NGOs, associations, foundations, research units).

Next, we depict two scenarios for the future transport systems with 5 and 10 year perspectives.

Five years perspective

All the transport modes will be evidently developed based on digital infrastructure and intensive utilization of collected data (Neilson et.al., 2019). This evolvement sets high requirements to the integration of transportation infrastructure and communication infrastructure. The communication networks will be used for the development of end-user services, professional services, maintenance of transportation network and management systems. In the following five years period the communication networks will be developed based on 5G technology, which brings several characteristics to advance the evolvement of the smart transportation system. Currently the 5G networks are under deployment in city centers and hot spots like airports, stations, shopping malls and stadiums. The 5G networks are mostly built by national MNOs probably utilizing their existing network grid and based on the earlier network deployments of 4G technology. Due to the higher frequency band of up to 26 GHz used in the 5G technology, the grid based on the lower frequency band of up to 2600 MHz in 4G network is probably too sparse for other purposes than basic network services like video streaming outdoors. To develop advanced real-time digital transportation services, it assumes deployment of dense 5G network topology and extensive IoT sensor infrastructure for data collection, integration, refinement and sharing. Dense networks are needed to utilize 5G technology capabilities like ultra-high data rate, low latency and powerful data processing by edge computing. Traditionally the business models of national operators do not though allow to adopt novel strategies of network deployment, but the networks are built based on co-siting with the previous network generations. This raises up a discussion about how to develop a smart transportation system if the current operator models of communication infrastructure deployments do not enhance to develop modern digital transport services. Another question comes from the IoT sensor infrastructure, i.e., what kind of stakeholders would it require to deploy such systems. There have been discussions, if there should emerge new market entrants or ecosystems to develop 5G and IoT networks to meet the requirements of the smart transportation vertical (Ahokangas et.al., 2018). The ecosystem model would be comprised of actors like cities, MNOs, infrastructure providers, network vendors, service providers and application developers, and the ecosystem would invest in the digital infrastructure acting like neutral host, who leases network capacity to operators. This development is seen as an alternative development to happen in five years period. Together with the ecosystem partners it assumes seamless co-operation with entrants, telecom operators and authorities for frequency licensing.

10 years perspective

The 5G era of 2020's will probably introduce the disruption of telecom market, when numerous new private and local networks will be deployed by new market entrants in parallel with the MNOs. Subsequently, the first 6G technology research programs have been launched to develop the next generation communication networks, which are anticipated to be deployed at the beginning of 2030's (Latva-aho & Leppänen, 2019). The 6G research programs are currently taking the first steps, and lot of things are still unknown. Several articles and white papers have been published about 6G, and they indicate new approaches of technological development, like human-centered technology, vertical-based applications and targets to reach the sustainable developments goals (SDG) by the United Nations utilizing 6G technology (Matinmikko-Blue et al., 2020). Advanced utilization of data and harnessing of artificial intelligence to develop hyper-local services have been also visioned to be in the core of 6G. For sustainability development, smart transportation will be probably one of the key verticals, where the 6G technology is first applied. This fits appropriately with the long-term visions and programs of smart transportation system development initiated by many nations and targeting to the 2030's.

The transportation system is being developed in Finland at national, regional, and municipal level. The transport system plan is an ongoing long-term strategic plan that reconciles the future needs of transport and land use acknowledging people, trade and industry as users of the system. The national plan compiles regional plans into a nationwide long-term plan while providing guidelines for new regional transportation system plans. National transportation system planning aims for over-government continuous activity to develop the transportation system. Preparation of the plan will take about two years. The plan is drawn up at a time for twelve years and is updated every four years with a change of government (see Figure 2). Regional transport system plans, on the other hand, are drawn up over a longer time span, allowing alignments and prioritizations to be made decades ahead, often e.g. 20 years away. While the fixed interaction between transportation system work and land use planning is considered a prerequisite for successful planning work, the challenge of coordinating transportation system planning and land use planning is often faced with faster development in the transport sector.

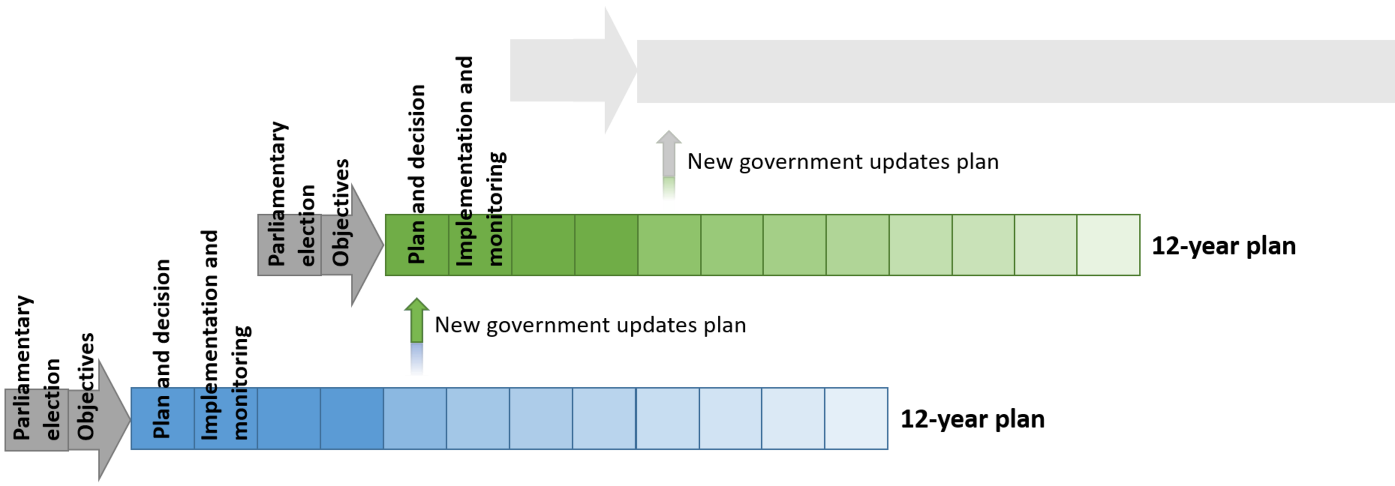

Figure 2. Nationwide Transport System Plan process and time-scales involved.

Land use planning processes are long. A strategic planning process may take several years (2-10 years) before the plan is legally binding. Detailed planning should be less time consuming (0,5-2 years). The time used in the process may vary a lot due to the success in participation and political decision-making. The project areas have also an impact on the process: the problems in infill development and new development vary a lot. Several parallel and sequential process are needed for the realization of the expected changes in the built environment: 1) urban design and planning (i.e. statutory plans) 2) land policy (land acquisition, plot division, land leasing and selling), 3) urban services (infrastructure) and 4) constructions (houses, streets, public areas). In conclusion, it may take up to 10-12 years to build a residential area (Figure 3).

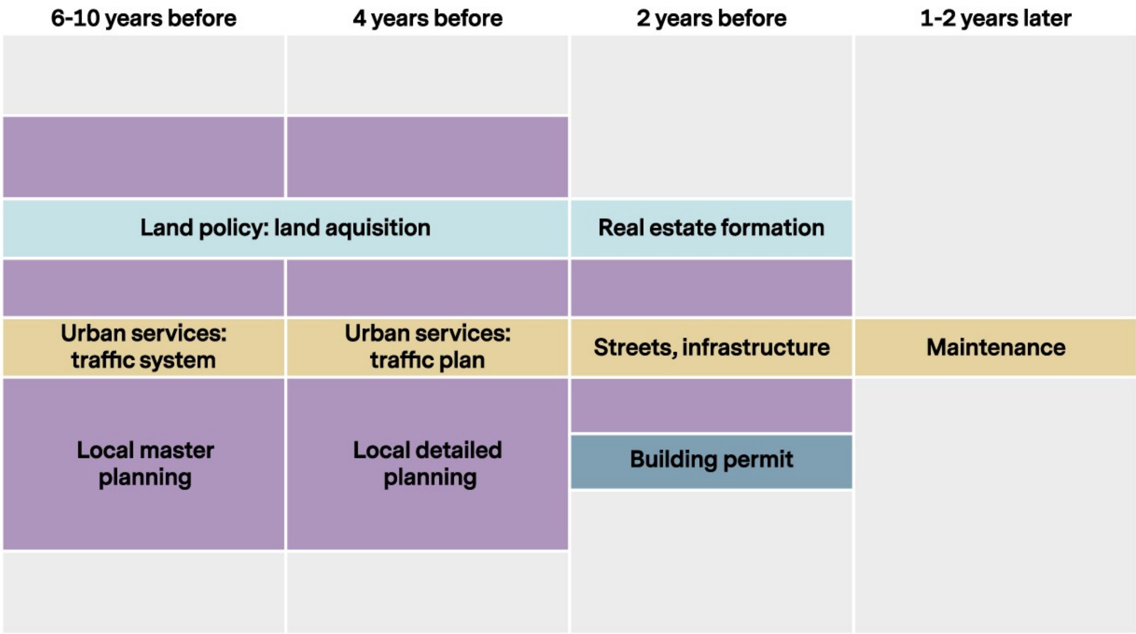

Figure 3. Processes of land use planning

The possible transition between different transportation modes varies a lot and the actions taken (network and timetable planning, pricing etc) may have unexpected results. According to Auvinen et al. (2020) the possible transition from one mode to another may take place during one tip and the transitions may impact on the individual’s future choices (Auvinen et.al., 2020) (Figure 4).

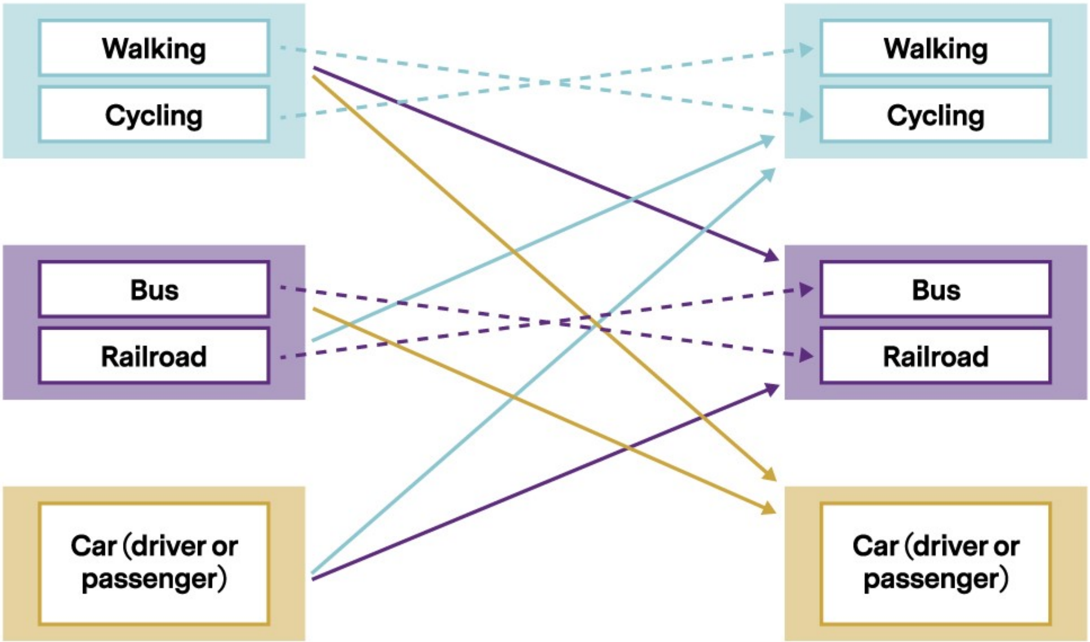

Figure 4. Potential transitions between transport modes

Based on the foreseen development of what is described above, the Figure 5 below illustrates the future smart transportation system with its entities. The transport infrastructure will be integrated with the communication infrastructure, which are managed through the system management functionality. The system management has also functions for storing, refining and sharing of data for various applications and services developed for different modes of transportation.

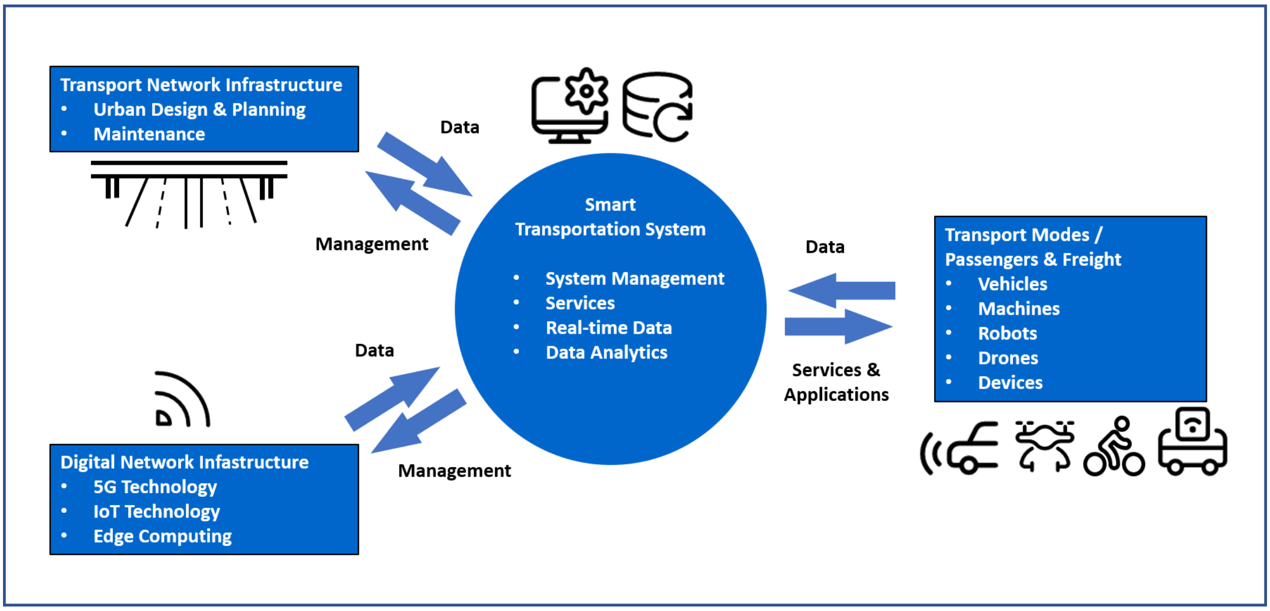

Figure 5. Illustration of data intensive smart transport system architecture

6. Identified Stakeholders

Next, we identify the key stakeholder involved in the development of future transport systems considering transport, urban design and planning and mobile communication perspectives introduced earlier.

Stakeholders in 5G/6G technologies

Evolvement of smart transportation system assumes to recognize the required stakeholders of various areas related to the development, deployment and operation of the system. Some of the stakeholders are required to contribute to the specification of the system, while others have role in planning and deployment of the holistic system. Another group of actors is still required to operate and maintain the system. The development of digital infrastructure covers 5G technology, IoT technology and data management expertise to be involved. Most of the actors have been introduced with their roles below.

Cities are strongly developing various smart concepts and services to inhabitants. Transportation is one of the key functions in any city to enable fluent and flexible everyday routines. Therefore, cities assumingly have the interest to specify and implement modern digital transportation services to residents and to increase attractiveness to receive new inhabitants and companies. City can be also one of the investors for the deployment of digital infrastructure, like deploying fiber optic cable networks for 5G technology or offering other infrastructure like lamp posts, traffic lights or traffic guides for digital infrastructure purposes.

Mobile Network Operator deploy, maintain and operate the 5G network infrastructure with edge and distributed computing capabilities and to offer advanced smart transportation services. The MNO may have an existing fiber optic infrastructure for data transfer. They (often) have country-wide networks that support mobility.

IoT service provider or **Data operator** plan, operate and develop the sensor infrastructure for data collection, validation, integration and sharing to enable the development of data-based transport services. Different stakeholders, such as MNO, can also act as IoT service provider.

Local operator can complement the 5G infrastructure and services offered by the MNO by operating a local 5G network in a specific location such as a campus area or a city, depending on the spectrum availability in the area. Instead of nation-wide MNO, the local operator may have more comprehensive topical knowledge to develop advanced and tailored digital services to inhabitants.

Network vendor delivers the network equipment, devices and software platforms to the operator for the implementation of 5G network. The vendor may have services for planning, maintaining and operating the network, which are allocated to the operator above.

IoT infrastructure vendor delivers the sensor systems to be deployed for collecting, refining and sharing the environmental data, and to be utilized by the transportation services and applications.

Application developers take care of programming applications, which can be used by residents to access data-based services. The applications can be used also for collection of data based on crowdsourcing model. The applications have significant role for positive end-user experiences in all transport modes.

National regulator is needed for granting the frequency license for the 5G network operation. The frequency license can be leased from the MNO or the local operator can have a dedicated license for themselves.

Stakeholders of Transportation System Planning

Development of the transportation system requires extensive cooperation between and within different organisations and close contact with residents, transport service producers and other users, and interest groups. Key players in transport system planning typically include relevant ministries and authorities and other public sector players, which vary in different countries. For the specific case of Finland, we can name the following key stakeholders: the Ministry of Transport and Communications, The Finnish Transport Infrastructure Agency, The Finnish Transport and Communications Agency Traficom, the Traffic and Communications Agency, the Ministry of economic affairs and employment, the Ministry of the Environment, Centres for Economic Development, Transport and the Environment, regional councils and municipalities. Stakeholders in regional transport system planning also include companies, organisations and chambers of commerce. As a broadly defined transport system plan, all entities and actors in society whose circumstances, activities or playing conditions are affected by the development of the transport system can be counted.

The Ministry of Transport and Communications is responsible for the development and transport strategies of the national transport network and prepares a statutorily nationwide transport system plan in cooperation with ministries, authorities and other actors key to the plan (the Act on the Transport System and Highways 503/2005 § 15). It also monitors and participates in provincial transport system planning and work and is responsible for contributing to the land use, housing and transport agreements (MAL) for large urban areas.

The Finnish Transport Infrastructure Agency is responsible for the design, maintenance and development of the road and rail network and waterways, and serves as an expert in trans-provincial, provincial and major urban transportation system planning and work. The agency is tasked with ensuring that regional transportation system plans implement nationwide alignments and strategic goals. In addition, the Finnish Transport Infrastructure Agency is involved in the preparation and implementation of MAL agreements. In transport policy alignments, the agency has preparatory and executive functions.

The Finnish Transport and Communications Agency Traficom's mission is to participate in transport system planning, in particular as an expert organisation for transport services, market functionality, promotion of automation and knowledge utilization. In the act on the Transport and Communications Agency (935/2018 § 2), the agency's tasks have defined, among other things, coordinating the preparation of national transportation system planning and implementing the plan, as well as generating and maintaining information for nationwide strategic programs, measures and the transportation system. Traficom is also involved in regional transport system planning along with other stakeholders.

Centres for Economic Development, Transport and the Environment (ELY centres) perform the executive and development functions of the state administration in their respective areas of operation. The ELY Centres transport and infrastructure responsibilities shall be responsible for the coordination and promotion of national, provincial, regional and local objectives and their practical implementation. ELY centres are responsible for monitoring the state of the transport system and are actively involved in provincial and regional level transport system planning. In large urban areas, ELY centres are involved in the preparation, implementation and monitoring of MAL contracts.

The Ministry of economic affairs and employment and the Ministry of the Environment influence the development of the transport system, mainly through the objectives of using and developing regions. The Ministry of Environment is also responsible for MAL contracts in conjunction with the Ministry of Transport and Communications.

In their regions, **regional councils** are responsible for the process of drawing up a transport system plan and the coordination of related cooperation, and coordinate planning with other provincial planning. This task is part of the strategic framework for regional development, for which provincial federations are statutorily responsible (the Act on the Development of Territories and Management of Structural Funds 7/2014, § 17).

Cities and municipalities are key players and contributors to the development and maintenance of transport infra. The municipality is responsible for the maintenance, management and development of the transport network for streets, car parks and often also for port areas.The objectives and views of other relevant entities will also be clarified in the development of the transport system. Means for interaction can include, for example, seminars, surveys, interviews, feedback channels, opinion tours.

Stakeholders of Urban Design and Planning

Land use planning concerns everyone and regulates development in the city. The process is open and participatory and involves various stakeholders. In Finland the Land Use and Building Act (Section 62) defines a stakeholder as follows:

[…] the landowners in the area and those on whose living, working or other conditions the plan may have a substantial impact, and the authorities and corporations whose sphere of activity the planning involves (*interested party*) […]

The identified *stakeholders* are listed in the participation and assessment scheme. The stakeholder group include residents, landowners, local and state authorities, public and private services, NGO's and companies. Accordingly, the stakeholders may have contradictory interest in the process and the process itself may be focused on certain interest superior to others.

In Finland Agreements on land use, housing and transportation (MAL) will be conducted in biggest urban regions (Helsinki, Tampere, Turku, Oulu) to "facilitate and support the cooperation between municipalities in urban regions and between municipalities and the State in the guidance related to the urban structure and coordination of land use, housing and transport" (Ministry of the Environment 2021).

Ministry of the Environment is competent ministry for the general development and guidance of land use planning and building activities in Finland. The Ministry of the Environment concludes negotiations on Agreements concerning land use, housing and transport (MAL).

Ministry of Transport and Communications is a stakeholder in a land use planning process if the plan concerns the area of the expertise. Is a partner in Agreements concerning land use, housing and transport (MAL).

Ministry of Economic Affairs and Employment, Ministry of Finance, is a partner in Agreements concerning land use, housing and transport (MAL).

Housing Finance and Development Centre of Finland (ARA) Is a partner in Agreements concerning land use, housing and transport (MAL).

Finnish Transport and Communications Agency Traficom is a stakeholder in a land use planning process if the plan concerns the area of the expertise. Is a partner in Agreements concerning land use, housing and transport (MAL).

Centre for Economic Development, Transportation and Environment (ELY) promote the organization of land use planning and building activity within the areas covered by a local authority. The ELYs must especially exercise control to ensure that national land use objectives, other goals pertaining to land use and building, and provisions concerning the management of planning matters and building activities are taken into account in planning, building and other land use. Is a partner in Agreements concerning land use, housing and transport (MAL).

Regional Council is in charge of regional planning which includes the regional scheme, the regional plan which steers other land use planning, and the regional development programme. The designated regional councils are partners in Agreements concerning land use, housing and transport (MAL).

Cities and Municipalities have the monopoly to draw up land use plans. They are entitled to make strategies and investments in the territory. They are in charge of street management including planning, building, maintenance, and cleaning and clearing of streets and other measure required to integrate the street area and the service conduits, equipment and structures both above and below it. They also grant building permits, deviations and action permits. Designated cities and municipalities are partners in Agreements concerning land use, housing and transport (MAL).**Teleoperators** are stakeholders in land use planning processes.

Landowners are stakeholders in land use planning processes.

Residents are stakeholders in land use planning processes.

Table 1. Expected contribution levels of stakeholders

Stakeholder Role *** Process leader ** Process contributor * Process follower	5G/IoT infrastructure	Smart Transport System	Urban Design & Planning
Cities and municipalities	*	***	***
Mobile network operator (MNO)	***	**	*
Local operator	***	**	*
Network vendor	***	**	*
IoT service provider	***	**	*
IoT infrastructure vendor	***	**	*
Application developers		***	**
Finnish Transport Infrastructure Agency		***	**
Ministry of Transport and Communications Agency	***	***	**
Centres for Economic Development, Transport and the Environment		***	***
Ministry of Economic Affairs and Employment		*	*
Ministry of Environment		*	**
Ministry of Finance			
Regional councils		***	***
Local authorities			**
Regional authorities			**
National authorities			**
NGOs		*	*
Landowners			**
Housing Finance and Development Centre of Finland (ARA)			**
Teleoperators			*

7. Recommendations and conclusions

This study has brought together transport, urban design and planning and 5G research domains for the first time to develop future transportation systems. These three domains need to interact in a close manner to realize the benefits of future ICT technologies in the development of future transportation systems in their application domain of cities and municipalities, and to design the future ICT solutions to meet the requirements arising from transport and urban design and planning.

Our study has depicted scenarios with 5 year and 10 year time horizons for the future transport systems and identified the key stakeholders in the three domains of transport, urban design and planning and ICT focusing on 5G. The resulting operational environment is very complex with a large number of stakeholders with different roles, which requires a careful examination of the key interactions between the three domains to find out concrete epochs to intervene. Our study has observed that the procedures and time-scales of the different domains vary and are not aligned. Urban design and planning involves long development cycles and specific procedures stemming from the laws. The development of a mobile communication generation on the other hand is industry-driven, typically taking 10 years from start of research into market deployment. Stakeholder involvement at correct time is critical and the development of future transport systems requires dialogues between the three domains. Therefore, more research is needed combining the three domains in the development of future transport systems making use of 5G/6G technologies.

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