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A Review on Societal Impacts of the Future Connected and Automated Transport Systems

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Abstract

Technical development in the field of vehicle automation is progressing rapidly, enhancing the expectation that connected and automated transport systems (CATS) will be introduced in increasing numbers over the next decade. The foreseen implementation of CATS has raised high expectations in terms of safety, environment, society and economic growth. The Horizon 2020 project Levitate will investigate the potential impacts of CATS, through an innovative multi-disciplinary impact assessment framework and will incorporate the method within a new web-based policy support tool to enable city and other authorities to forecast impacts of CATS on urban areas. The objective of this study is to provide a review of future impacts of CATS, through an extensive targeted review of recent literature on the impacts of connected and automated urban transport, passenger vehicles and freight transport, as well as a comprehensive analysis build on the knowledge gained through existing European level research.

Keywords: connected and automated transport systems; public transport; passenger vehicles; freight transport; impacts; penetration level

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1. Introduction

Next decade seems promising regarding the introduction of connected and automated transport systems (CATS), as technology progresses rapidly in the field of vehicle automation. More specifically, it is expected that, the 73% of new cars and trucks will be connected by 2020 (GEAR 2016) and that by 2030, 25% will have at least SAE L4/5 automation level and the remainder will be at L3 (KPMG 2015). The introduction and full implementation of CATS on urban areas in the near future has raised high expectations in terms of reduction of traffic congestion, road crashes and vehicle emissions. Connected vehicles using V2V, V2I and V2X systems, will operate more efficiently, optimising journey time, also affected by the increasing deployment of applications based on the mentality of Mobility as a Service. Additionally, the novel business schemes and services (operators and remote control centre, algorithms developers, cybersecurity and data analysis experts, etc.) will result in new business that will surpass the current loss of jobs due to eventual redundancy of the driver.

The automated era might also have potential shortcomings, especially during the transitional phase, where conventional and automated vehicles of different levels of automation will share the road. The interaction of CATS with conventional vehicles and with vulnerable road users is expected to introduce new safety risks. Furthermore, CATS are expected to significantly reduce chances of human error, reduce the impact of distracted driving, and reduce the occurrence of conflict situations leading to collisions. However due to the high complexity and dynamics of the road environment, including mixed traffic situations, significant challenges still remain. In some situations, a human driver will encounter situations that he or she is not prepared for: After a time period of not being involved in the driving process, the driver of SAE L3/4 will have to come back into the loop and take control of the vehicle, in case of unplanned critical situations during automated driving (SAE, 2018). Additionally, while vehicle automation is expected to empower social mobility for the less privileged, and citizen groups with special needs, it could have a rebound effect of increasing traffic and road use by up to 14% (Corey et al., 2016) with the related negative environmental impact.

Since CATS are still an emerging technology, their implementation impacts on several areas are still unclear, due to lack of data. The H2020 Levitate project (https://levitate-project.eu/) aims to prepare a new impact assessment framework to evaluate the impact of different technologies, scenarios and interventions by city/regional authorities, with the aim to capture the benefits of automation and ensure that new technologies will contribute to policy objectives. In that context, the objective of this study is to provide a comprehensive review of future challenges of connected and automated transport systems, with particular focus on three primary use cases: automated urban transport, passenger cars and freight transport. To this purpose, a preliminary review of recent literature has been conducted on the impacts of CATS that includes published reports, research papers and research project deliverables from the EU, USA and other international sources. Also, the results of a workshop facilitating extensive stakeholders' consultation are discussed: municipal and regional authorities, transportation industry and experts.

2. Review Methodology

The targeted literature review methodology is based on the following steps, detailed in the sections below:

i. Taxonomy of impacts
ii. Literature review and study selection criteria
iii. Template for coding studies
iv. Synopses summarising results of impacts for each use case
v. Quality assurance

2.1. Taxonomy of impacts

In order to provide a structure to assist in understanding of how CATS impacts will emerge in the short, medium and long-term, a preliminary taxonomy of the potential impacts of CATS was developed by Elvik et al. (2019). This process involved identifying an extensive range of potential impacts which may occur from the future expansion of CATS. A range of impacts were classified into three categories, direct impacts, systemic impacts and wider impacts. Direct impacts are changes that are noticed by each road user on each trip. These impacts are relatively short-term in nature and can be measured directly after the introduction of intervention or technology. Systemic impacts are system-wide impacts within the transport system. These are measured indirectly from direct impacts and are considered medium-term. Wider impacts are changes occurring outside the transport system, such as changes in land use and employment. These are inferred impacts measured at a larger scale and are result of direct and system wide impacts. They are considered to be long-term impacts. The draft taxonomy will be systematically evaluated and become more extensive during structured workshops, where stakeholders will be asked to prioritise and indicate missing topics. In view of the literature review, all impacts have been divided in four high-level impact areas: safety, environment, society and economy.

2.2. Literature review and study selection criteria

For each of the aforementioned high-level impact areas and for each use case (urban transport, passenger vehicles and freight transport) a standardised literature search has been conducted. In order to identify an adequate and reasonable number of relevant studies for each use case, Levitate partners have been querying all available scientific literature databases such as Scopus, Google Scholar, Web of Science etc. The potentially relevant papers, reports and project deliverables, were screened to assess their eligibility for further analysis, starting on the basis of the abstract and then on the basis of the full paper. Special attention has been given to studies providing a quantitative (or qualitative) estimate of the impacts of each use case.

2.3. Study coding template

The selected studies were individually coded in an Excel coding template. The coding template required the researcher to provide information in predefined categories, such as the impact area covered by the study, the addressed use case, user types etc., where entries were restricted to a specific range of values. Additionally, the reviewers had to indicate the methods used for the impact assessment and if the study presented quantitative results that could be used in the next phases of the project. Finally the reviewer had to rate the importance and the quality of potentially relevant studies, according to his judgement on how relevant and important is the content of the study for the project.

2.4. Synthesis summarising results of impacts for each use case

Once all the studies in an impact area have been recorded, the results in terms of CATS impacts have been summarised in a short report referred to as a Synthesis. Each synthesis is designed to be understandable for an educated non-expert audience and includes:

- Summary: Brief report of the background of the impact area on the specific use case, the main results and conclusions based on the analysis
- Literature review: Including the scientific overview of the estimated impact area
- Impact assessment methodology: a full analysis of the methods used for the assessment of the targeted impact area
- Studies data and results: presenting an overview of the data used for the impact assessment and analysing transferability conditions and results
- Studies results: containing a detailed presentation of the results

2.5. Quality assurance

The scientific quality of contents of the literature review has been ensured by putting in place strict quality assurance procedures. All guidelines concerning the collection of papers, reports and project deliverables were comprehensively circulated to those completing the literature reviews and peer review process was established within the project. The literature review outputs were also checked by independent experts. Finally, all synthesis documents went through a language check by a native speaker.

3. Results

The relevant papers, reports and project deliverables taken into consideration for the literature review are presented in detail in the project deliverables concerning each use case (Boghani et al.,2019, Hu et al., 2019, Roussou et al., 2019). The synthesis of the obtained results indicated that the penetration level will dictate the impact of the introduction and adoption of CATS. More specifically, for each use case the future challenges differ as follows.

3.1. Public Transport

3.1.1. CATS technology within public transport

Public transport consists of buses and other vehicles on the road, but also includes rail-bound services. The International Association of Public Transport (UITP) defines five grades of automation (UITP, 2012). Grade 0 is the conventional train operation in ordinary roadways, Grade 1 combines train control and manual operation (the driver operates the doors, starts and stops the vehicle, but some parameters of the trip can be managed by a train control), in Grade 2 the driver starts the vehicle and control the doors, while the trip is in a semi-automatic train operation (STO), Grade 3 constitutes the driverless train operation (DTO) where there is only a train attendant to take control in the event of emergency and Grade 4 is the unattended train operation (UTO, or manless train operation MTO) where all the operations are automated and there is no staff on the vehicle while only the control centre can intervene. Furthermore, regarding the road traffic, according to the J3016 standard (SAE International, 2016), there are six levels of automation: no automation (0), driver assistance (1), partial automation (2), conditional automation (3), high automation (4) and full automation (5).

Public transport constitutes a significant element of urban mobility (Pakusch & Bossauer, 2017) as it can **alleviate congestion issues in cities and promote sustainability**. According to VDV (2015), there are two extreme **scenarios** describing the uptake of CATS as far as urban transport is concerned. According to the **pessimistic** scenario, **public transport will suffer due to the focus on autonomous private cars**, whereas, according to the **optimistic** one, **shared autonomous cars will be fully integrated into public transport** and provide great coverage for all regions of the city, thus rendering private cars superfluous.

3.1.2. Automated public transport impacts

The large-scale introduction of CATS in urban environments will affect fundamentally urban transport and space (Fraedrich et al., 2019). The benefits from fully automated public transport could include reduced crash rate, increased punctuality, shorter headways and greater availability (Pakusch & Bossauer, 2017). Under these circumstances, a greater proportion of people are expected to be using public transport. Nevertheless, the role of AVs for public transport can be controversial. On one hand, by providing first and last mile services, AVs can boost the use of other transport systems by providing efficient door to door transport. On the other hand, they raise this unique advantage of the public transport. Therefore, transport modal split could be affected, and public transport suppliers would face challenges as serious reconsideration would be required for existing business plans. These changes in modal split could lead to congestion unless changes in road network also take place (Boesch & Ciari, 2015). A study by Owczarzak and Żak (2015) compared several public transport solutions in relation to AVs and regular urban transport and concluded that the combination of AVs with the urban bus system is expected to increase travel comfort by reducing crowdedness, reduced travel costs and increased availability, timeliness and reliability of transportation service. The authors stated that the operation of AVs in public transport systems could be beneficial towards their efficiency and effectiveness of the latter.

The concept of Mobility as a Service (MaaS), has proved to be a key feature to lead towards a successful implementation of automated urban transport (Mulley & Kronsell, 2018), that could limit the negative effects of road transport (European Commission, 2017), as long as it promotes car sharing, ride sharing or sourcing and not private mobility solutions. According to Firnkorn and Müller, (2015), automation could attract more people to car sharing for the first or last mile of their trip instead of walking, cycling or using a private car. Automated urban transport can be seen as one of the main solutions to achieve vision zero that the majority of European Countries has set for the next decades, as shifting from private cars to public transport will lead to safer cities. Society, will benefit from the implementation of automated vehicles, as being efficient, economic, safe and comfortable contribute to a balanced society (Gorris, et al., 2012). Automated urban transport can contribute to urban sustainability, but available and future technologies must be adapted to the specific location, time and space to achieve successful implementation.

3.2. Passenger vehicles

3.2.1. AVs technology evolution

Automated driving includes a wide range of different technologies (OECD/ITF, 2015). According to SAE (2018), CATS are divided in five levels of automation additional to baseline unautomated driving. Automated levels 1 and 2 are used by the driver to provide support with dynamic driving tasks and driver can activate, deactivate and override them at their will, as s/he remains engaged in the dynamic driving task (UNECE, 2017). These systems called ADAS (Automated Driver Assistance Systems) encompass different functions such as, Adaptive Cruise Control (ACC), Lane keeping Assistance Systems, Remote Control Parking, etc. These functions are available in most modern cars of today. In contrast to levels 1 and 2, automation levels 3, 4 and 5 perform the dynamic driving task. However, level 3 and 4 may require the driver to monitor the driving environment, retake control or perform the strategic driving task. More specifically, Automated Vehicles (AVs) of level 3 perform the dynamic driving task in specific use cases and the driver is asked to retake control at any time when system encounter an unknown situation. The level 4 AV system performs the dynamic driving task in some environmental conditions, even if the driver does not respond appropriately to a request to intervene. However, not all environmental conditions are expected to be covered by level 4 AV system. Finally, in automation level 5 the vehicle performs all dynamic driving tasks during its entire journey and the driver can perform other non-driving related activities.

3.2.2. AVs expected impacts

The DriveC2X project provide some estimates of accidents reduction due to the use of Cooperative Intelligent Transport System (C-ITS) services. The project conducted field demonstrations at several test sites across Europe and then held a safety and efficiency assessment of C-ITS services. These services include: In-vehicle Signage speed limits and other signs, Obstacle Warning, Road Works Warning, Car Breakdown Warning, Traffic Jam Ahead Warning, Green Light Optimal Speed Advisory Weather Warning, Rain and Slippery road/Ice&Snow, Approaching Emergency Vehicle and Emergency Electronic Brake Light. The safety impact assessment of the aforementioned C-ITS applications was carried out in both fatal accidents and injuries for the years 2020 and 2030 (Malone et al., 2014). The most effective service in terms of accidents reduction was speed limit warning through In-vehicle signage (IVS), preventing 16% of fatalities and 8.9% of injuries. The other C-ITS services resulted in a reduction of 0.1%-3.4% of fatalities and a reduction of 0.2%-3.3% of injuries.

The introduction of automated driving of levels 3, 4 and 5 is expected to bring significant safety benefits, especially as the level of automation increases. According to Logan et al. (2017), the US Federal Highway Administration predicted that 50-80% of highway crashes could be eliminated with the adoption of Automated Highway Systems. AEB for example, has been found to reduce all rear-end crashes by 35% to 41%. A more general assessment is provided by Fagnant and Kockelman (2015) who suggested based on the fact that more than 40% of fatal accidents in the US are due to alcohol, distraction, medication and/or fatigue, CATS not affected by these factors could have the potential to contribute at a reduction of at least 40% in fatalities. A report by the NSW State Insurance Regulatory Authority (Finity Consulting, 2016) estimated that the wide adoption of automated vehicles in Australia would reduce the chance of injuries for drivers and passengers by 80%, of cyclists by 70%, of motorcyclists by 40% and pedestrians by 45%.

Using the automation technologies of levels 2 – 5 (eco-driving – for example, speed control, smooth and gradual acceleration and deceleration) are expected to improve fuel economy. Eco-driving can improve fuel economy by 4% to 10% (National Research Council, 2013). In addition, since connected systems can optimise traffic flow and reduce the distance required for safety between vehicles, there may be an increase in the capacity of travel lanes and a reduction in congestion fuel consumption. Folsom (2012) estimated that a fleet of automated vehicles could lead to fuel consumption up to 0.47 to 0.235l/100km.

The implementation of CATS is expected to lead to lower travel costs, higher user comfort and increased accessibility to different groups, resulting in an increase of vehicle kilometers travelled per day. The increased accessibility due to the wider adoption of automated vehicles, especially given the fact that AVs may allow disabled people to travel the same distance and do same number of car journeys, it could lead to an increase of the average kilometers covered per day by more than 50% (Meyer & Deix, 2014). Brown et al. (2014) used data from the NHTS 2009 (National Household Travel Survey, conducted by the Federal Highway Administration (FHWA)) and the 2003 Freedom to Travel project to estimate the increase in travel for young people, the elderly and the disabled. There was a total increase of 40% of vehicle kilometers travelled (VKT) per vehicle due to automated driving. Milakis et al. (2017) reported a potential increase of VKT of 3% to 27% for various automated vehicle deployment scenarios in the Netherlands.

The wide adoption of automated passenger vehicles is expected to have a profound and prolonged impact on land use (Bagloee et al., 2016). More specifically, literature suggests that there are two leading theories for potential impacts, either the implementation of CATS will contribute to a more dispersed and low-density land-use, due to the improved geographic accessibility and the reduced travel time, or the reduced need for parking spaces, will stimulate urban growth in central districts (Heinrichs, 2016). Additionally, the potential congestion in major cities in the short term, due to the increase of VKT and to the increased accessibility, could lead to higher energy consumption. In order to promote more efficient land use and use of resources, achieving environmental sustainability, it is suggested to implement road use pricing, where prices are applied into different segments offering traffic load balancing.

Most studies report that CATS could increase travel demand by 3% to 27% due to changes in destination choices (for example, longer journeys), changes in transport mode (shift from public transport) and the introduction of new users. According to the outcomes of hypothetical and realistic simulations in the city of Zurich, one shared automated vehicle could replace about 10 to 14 conventional vehicles (Boesch et al., 2016; Zhang et al., 2015). The International Transport Forum (2015), simulated different scenarios of automated transport systems, penetration rates and availability of high-capacity public transport. This report stated that shared automated vehicles could replace all conventional vehicles, offering equal levels of mobility with up to 89.6% (65% during rush hour) fewer vehicles on the roads.

Concerning social sustainability, in the short- and medium-term future the high cost of owning a private automated vehicle could lead to social inequality for the low-income groups (Milakis et al., 2017). The concept of Mobility as a Service could be a solution to this problem. In the long term, full penetration of AVs, as well as investment in automated public transport could ensure social equity and accessibility for all social groups. Additionally, public health is an important factor taken into account when designing the future for AVs. Given the fact that AVs offer the possibility of comfortable door-to-door travel, other modes of transport, such as walking and cycling, could be abandoned leading to a decrease of public health due to a sedentary way of life (Cohen et al., 2017). A medium or long-term policy, when penetration rates of AVs will be higher, could be to delimit AVs access to certain zones, promoting other healthier modes of transport.

Concerning the impact on the economy of the deployment of CATS, the estimated overall economic benefits due to reduction in accidents and in travel time, fuel savings and parking facility, could amount from 2000$ to 4000$ per vehicle per year (Fagnant & Kockelman, 2015). According to a US Department of Transportation investigation (U.S. Department of Transportation, 2017) the wide adoption of CATS can lead to a reduction of fuel consumption of up to 50%, reduction of emissions from 12% to 50%, reduction of travel time from 12% to 48%, reduction of journey delays up to 85% and save significant number of lives every year. Even though, automated passenger vehicles, contribute to safety and environmental improvement, sustainability and shared mobility should be promoted in order to ensure a healthy city region.

3.3. Freight transport

3.3.1. CATS technology within freight transport

The Connected Automated Driving Roadmap (ERTRAC 2019) focuses on level 4 (highly automated) commercial freight transport vehicles for operation in dedicated areas. The main applications are hub-to-hub transport, transport on highways, open roads, and in urban areas. The development can be summarised in these main steps:
- Level 1 and 2 will bring small shifts from driver-controlled variables to automated ones, which mainly contribute to safety benefits.
- Level 3 will bring significant changes since most of the miles can be driven autonomously on the highway. The driver is required in case of subpar weather events that limit connectivity and/or visibility.
- Level 4 vehicles will take on hub-to-hub transports and operate in designated corridors. These can either be highly automated trucks with driver cabin or potentially also unmanned vehicles with remote support / supervision.
- Level 4 vehicles will perform automated operations on open roads in urban environment and handle mixed traffic in all typical scenarios without driver intervention.

3.3.2. Automated freight transport impacts

The Connected Automated Driving Roadmap (ERTRAC 2019) states that CATS will provide the opportunity to revolutionize the trucking industry and the way fleets operate. If used properly, automated commercial freight vehicles could improve fleet efficiency, flexibility, and particularly operation costs. It has also great potential to effectively reduce traffic congestion-related costs through vehicle platooning, improve driver behaviour, reduce driver costs, and increase fleet mobility as well as safety.

Safety is a critical issue since freight related vehicles, largely composed of trucks, vans and other large vehicles, have the potential to cause severe crashes. The fatality rate of crashes involving freight related vehicles is relatively high compared to the number of collisions (Eurostat 2015). This is the main driving factor behind the development of ADAS that intend to address safety impacts. Beyond ADAS, the introduction of level 3 and level 4 automation, especially in urban areas, still requires substantial research and tests. ERTRAC (2019) states that technology must be proven to ensure functioning without any problems in various climates and traffic conditions and that during the transition phase, trials in a controlled or specific area at specific times should be encouraged.

Labour currently accounts for an estimated 35 to 45% of operating costs of road freight in Europe (Panteia, 2015). ERTRAC (2019) states that CATS provide the opportunity to revolutionize the trucking industry and the way fleets operate. If used properly, automated commercial freight vehicles could improve fleet efficiency, flexibility, and the total cost of ownership. According to the IRU report ‘Managing the Transition to driverless road freight transport (2017), the operating cost reductions are likely to be significantly higher in long-distance freight where drivers will account for a greater share of the cost base than in urban freight. Overall, operating cost reductions for long-distance freight in the order of 30% are possible under driverless operation. This will pave the way for new business models and logistic concepts.

For freight transport, vehicle automation does not necessarily lead to direct environmental impacts per se. ERTRAC (2019) identifies vehicle design, drivetrain, energy composition, and operational efficiency as main factors for the sustainability of freight transport. It should be noted though that these factors are not necessarily directly connected to CATS. Essentially, there is not much of a difference between achieving the freight volume (expressed in tonne-kilometers) by vehicles driven by conventional drivers or automated transport.

However, CATS do contribute to environment impact in a broader sense. For platooning, lots of scientific research has been done and they indicate that it can reduce the fuel consumption (e.g. Mello 2019). For drivetrain and energy, there is a correlation between E-mobility and CATS on the level of technology innovation. Therefore, CATS indirectly reduce CO2 emissions – if electric energy is generated in an environmentally friendly way. New business models and logistic concepts enabled by CATS will likely increase the operational efficiency and therefore reduce energy consumption in general.

CATS will have a huge impact on truck drivers. On the one hand, truck driving is not considered as an attractive job in general because of the modest payment, exhausting long-haul trips, and hard to combine with family life. Professional drivers often are on consecutive trips that last for several days, which causes them to have very limited availability for family and personal matters (Costello, 2017). On the other hand, there are concerns that with CATS, millions of truck driver jobs are at the risk of being eliminated since they can be automated relatively soon (Frey et al 2017). This topic is very controversial though and there are studies pointing out that the loss of truck-driving jobs is overstated. Arguments are that only the job profile would change: “Drivers” will take over non-driving tasks which are still at high demand, while the long-haul trucking will be automated (Gittleman et al 2019). If this is true, CATS will bring benefits for the drivers and will not eliminate them. They will take over the short-haul and the last mile trips, therefore they can work in the area that they live.

For end-consumers the changes with the introduction and penetration of CATS in freight transport are less significant. As long as the service quality is guaranteed, the wider population probably does not know or care about the logistic supply chain behind the packages that are delivered to them.

4. Conclusions

The Horizon 2020 project Levitate aims to create a new impact assessment framework to enable cities and other authorities to forecast impacts of CATS on urban areas. The first step, in order to establish a comprehensive impact assessment methodology, is a detailed review of relevant literature to identify the future of CATS and how each impact area will be affected by CATS in urban transport, passenger vehicles and freight transport. The results of the literature review were validated and enriched by the stakeholders' workshop, where municipal and regional authorities, transportation industry and experts were asked about their first thoughts on future cities and CATS as well as their main principles for future planning. The outcomes of the review indicated that CATS benefits and shortcomings depend on, the penetration level, time, location of implementation and relevant policies. For this reason, policy objectives should take into consideration all relevant factors in order to achieve a successful and beneficial implementation of CATS, in each one of the studied use cases.

5. Further development

The results of Levitate will be made available through an open access web-based Policy Support Tool (PST), in order to provide future users with access to Levitate methodologies and results. The detailed design will be informed by the specific needs of the key stakeholders and it will provide access to related bibliography, project results, documentation of tools and methods, excerpts from CATS guidelines, as well as a Decision Support System with forecasting and backcasting capabilities. The Levitate PST will comprise two main modules; the knowledge module and the estimator module.

The knowledge module will provide access to the knowledge base, repository and guidelines of the Levitate project. The estimator module will provide estimates for different types of impacts and allow comparative analyses. It will include the forecasting sub-system, that will provide quantified and/or monetised output (depending on the impact) on the expected impacts of CATS related policies, using both pre-defined key scenarios and customised scenarios, and a backcasting sub-system that will enable users to identify the sequences of CATS measures that will most likely lead to their desired policy objectives.

The results of the literature review will provide input to the CATS-PST knowledge module, that will contain the excel coding template for relevant literature as well as syntheses on the key impact areas for each one of the three use cases. Finally, the outcome of the literature review will provide the necessary values and formulas for the implementation of the CATS-PST estimator.

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