Synopsis of wider impacts of Cooperative, Connected, and Automated Mobility

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Summary

The impacts to be studied in the LEVITATE project have been defined in Deliverable 3.1 (Elvik et al., 2019) which provides a preliminary taxonomy of the potential impacts of Cooperative, Connected and Automated Mobility (CCAM). A range of impacts were classified into three categories, direct impacts, systemic impacts and wider impacts. **Direct** (short term) 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** (medium term) impacts are system-wide impacts within the transport system. These are measured indirectly from direct impacts and are considered medium-term. **Wider** (long term) impacts are changes occurring outside the transport system, such as changes in land use and employment. These are inferred impacts, considered to be long-term, measured at a larger scale and are result of direct and system wide impacts. This synopsis discusses the wider impacts assessed within LEVITATE.

Mobility technologies and services can be implemented in many ways; however, the prioritisation, within LEVITATE, of the studied policy interventions (sub-use cases) for impact assessment mainly took input directions from

1. **Scientific Literature**: indicating the scientific knowledge and the available assessment methodologies for the sub-use cases. However, this theoretical approach might not be directly linked to their importance or relevance for practice.
2. **Roadmaps:** indicating the relevance of sub-use cases from the industrial or political point of view, independent of available scientific methodologies.
3. **Stakeholder Reference Group (SRG) Workshop:** Containing first-hand feedback for the sub-use cases but might only reflect the opinions of organisations and people who participated, and
4. Results of the **backcasting city dialogues** conducted in LEVITATE WP4 for Vienna, Greater Manchester and Amsterdam (Zach, Sawas, Boghani, & de Zwart, 2019; Papazikou et al., 2020)

The wider impacts studied for the automated **urban transport** sub-use cases are parking space demand, road safety, energy efficiency, emissions, public health, accessibility in transport and commuting distances. For automated **passenger cars** sub-use cases (SUCs) the wider impacts are the demand for parking, road safety, energy efficiency, emissions, public health and commuting distances and finally the wider impacts related to the introduction of automated **freight transport** were road safety, emissions, parking space, energy efficiency and public health. The studied automated urban transport SUCs are the point-to-point Automated Urban Shuttle Service (AUSS) and the on-demand AUSS (which included the anywhere-to-anywhere, last-mile and e-hailing services). The automated passenger cars SUCs are road using pricing, provision of dedicated lanes for connected and automated vehicles (CAVs), parking price regulations, replacing on-street parking, automated ride sharing and Green Light Optimal Speed Advisory (GLOSA). The automated freight transport SUCs are automated urban delivery, automated freight consolidation and hub-to-hub automated transport.

All the aforementioned wider impacts have been estimated and forecasted using appropriate assessment methods based on D3.2 (Elvik et al., 2019) and on feasible paths of interventions defined by D4.3 (Zach et al., 2019). The methods used to identify the wider impacts of the introduction of CCAM in the urban environment are the microscopic

simulation, , operations research, surrogate safety assessment method, system dynamics and the Delphi method. The results have been integrated within the LEVITATE Policy Support Tool (PST) modules and functionalities so that the impact assessment can be carried out by the users.

Wider impacts

Demand for parking

System dynamic model results indicated an increase in demand for parking with increasing market penetration rate (MPR) in the baseline scenario, reaching more than 40% extra at full fleet penetration due to the increased share of private cars. However, with some disagreements, the majority of the experts' opinions in this regard (through the Delphi study) indicated the reduction in parking demand in urban environment with increasing market penetration rate (MPR) of CAVs, which might be explained by implicit consideration of effects like empty AVs driving around or increased shared mobility.

Implementation of parking space regulations involving the removal of 50% on-street parking would likely have a negative impact on automobile travel and lower the demand for parking as compared to the baseline condition. On the other hand, the policy intervention of conversion to driving lanes would likely lead to an increased travel demand (as compared to 50% parking space removal) due to encouraging additional vehicles on road. In comparison with baseline, the increase in parking demand will potentially occur with increased automation (at least 50% or above). General experts’ opinion in this regard indicated that the introduction of parking regulations will progressively reduce parking spaces required.

Under parking pricing, policies resulting in a mixture of parking behaviours were analysed. As expected, this policy intervention is estimated to significantly reduce demand for parking as compared to the baseline with the relative demand for parking space staying constantly slightly above 20% with increasing MPR. Majority of the experts' opinions in this regard also suggested that the CAVs parking behaviour would reduce the requirement of parking spaces. CAVs parking inside the city centre would decrease the parking demand up to 40%. The requirement of parking spaces for CAVs returning to origin, driving around and parking outside scenarios will be reduced by 19.7%, 36.2% and 12.2% respectively for 100% AVs market penetration rate.

The road use pricing policy implementation was estimated to significantly reduce the demand for parking space. Delphi study results also indicated the same effect with road use pricing strategies while empty km pricing was predicted to cause the maximum reduction in the long-term reaching up to 11%.

Majority of the experts predicted reduction in parking demand with inclusion of services like automated ridesharing (ARS), almost by 25% as found through the Delphi study. However, system dynamics modelling of ARS results indicated almost no change in parking demand as compared to the baseline, on the basis of ARS providing a 20% share of total demand and 100% willingness of passengers to share. Intuitively, more demand served by shared CAVs would reduce the number of personal vehicles cars on the road. However, due to pick-ups, drop-offs, and waiting for passengers, the requirement for parking spaces may not significantly reduce.

Regarding automated urban transport, when penetration rates of automated vehicles reach 80-100% in the baseline scenario, compared to the situation with only human-driven vehicles and no CAVs, parking space is expected to have a reduction of 18%-21% according to Delphi panel and a 35-47% increase according to System dynamics. The system dynamics model predicts that last-mile AUSS can reduce parking space demands to levels lower than the baseline.

The automated freight transport measures such as automated delivery or hub-to-hub automated transport are expected to require more parking space than the baseline. According to expert consultation, in the baseline scenario parking space requirements will be reduced by nearly 12% once human-driven vehicles are reduced to 20% or lower. Looking at the impacts estimated for the three freight sub-use cases, all three are associated with a reduction of required parking space. However, in all cases the impact is smaller than in the baseline, implying that the automated delivery van SUCs will require more parking space than the scenario with automation but without a fully-automated, unstaffed delivery van system.

Energy efficiency

The impact on energy efficiency within the LEVITATE project refers to the energy consumption of vehicles during operation only, and not related to their manufacturing and disposal.

The impact on energy efficiency due to increasing CAVs in the transport system as well as with various policy measures was estimated through Delphi panel study. Overall experts predict improvement in energy efficiency with the increment in market penetration of CAVs (baseline). All road using pricing schemes were predicted to improve the energy efficiency. More specifically, it was indicated through the Delphi results that the increase in energy efficiency could be increased with the introduction of a dynamic city toll by up to 15%, while a static city toll can potentially increase energy efficiency by almost 11% in the short term and 7% in the long term. The increase in energy efficiency, taking account of empty km pricing, was predicted to be up to 10%.

The Delphi study findings on the impact of dedicated lanes for CAVs on energy efficiency indicated no impact to a slight reduction in the short term (under different placement scenarios) but an increase can be expected in the long term only for AVs market penetration rate higher than 60%, leading to a maximal increase of 6%. Under various configurations, the innermost motorway lane was indicated to improve energy efficiency the most leading to an increase by almost 11%.

Under the given on-street parking replacement options, most of the experts indicated that replacing on-street parking space with space for public use will improve energy efficiency the most i.e., by almost 13%. However, replacement of on-street parking space with driving lanes or with pick-up/drop-off spaces will both negatively affect energy efficiency. With regards to parking price policies, majority of the responses gathered through the Delphi study indicated improvements in energy efficiency with parking price policies that were tested except the drive around strategy. The improvement was indicated to be 29% for 'park inside' (the city centre), 16% for 'return to origin', and 14% for 'park outside' scenario at 100% MPR of CAVs. On the other hand, CAVs driving around will potentially have a negative impact on the energy efficiency, reducing it by almost 14%.

Automated ride sharing services are also expected to strongly impact energy efficiency potentially improving it by almost 22%. Most of the experts predicted the largest impact on energy efficiency due to implementation of GLOSA, with an expected increase of almost by 31%.

For automated urban transport, both the outcomes from microsimulation and Delphi method showed that there could be an improvement in resource efficiency and a reduction in energy demand. It should be noted that point-to-point AUSS, seems to present higher positive impacts on energy efficiency.

For automated freight transport, the wider impacts on energy efficiency were based on a two round Delphi panel where results indicated an improvement with increasing AV penetration rate. According to the experts, the baseline development of the energy efficiency of freight vehicles (used for road transport) is positive; in the baseline, energy efficiency improves by 6% to 16% once human-driven vehicles are reduced to 60% or lower of the vehicle fleet and replaced by first- and second-generation CAVs. The expected impacts on energy efficiency of the three-freight service SUCs, namely automated delivery, automated consolidation and hub-to-hub, are all positive. Compared to the baseline development, experts estimate that the introduction of automated delivery, automated consolidation and hub-to-hub in freight vehicles will further improve energy efficiency. Especially the estimates for automated consolidation are positive with energy efficiency being 1.5 to 2 times higher compared to the baseline.

Emissions
Microsimulation results showed a significant reduction in emissions as CAV MPR increased, primarily due to powertrain electrification considered in the models for CAVs. However, the impact of various interventions tested was also analysed by determining the percentage difference with intervention vs. no intervention (baseline) case under mixed fleet scenarios with human driven vehicles. The dedicated CAV lane configurations, tested on an A road and a motorway within the Manchester network, exhibited reductions in emissions on average; however, the percentage reduction fluctuated across the different implementation strategies and MPR scenarios. Percentage reduction in particulate matter (PM) emissions was found to be more than CO2 and NOx emissions.

Under parking price policies, it was found that parking strategies can strongly influence the vehicular emissions, especially PM proportions. Surprisingly, the microsimulation results showed maximum reduction in overall emissions under ''Drive around'' parking behaviour as compared to ''return to origin and park outside'' and ''balanced'' parking behaviours scenarios. However, the major reduction of emissions in drive around case is attributable to the reduced traffic flow and lesser number of vehicles in the network within analysis (simulation) duration. The balanced option in this regard was found to be the optimal one as compared to others. The results of the parking space regulations SUC from microsimulation showed that the emission for all three indicators CO2, NOx and PM reduce dramatically as the CAV fleet penetration level increases. This is mainly because of the electric powertrain considered for all CAVs within the project. However, if CAVs were considered non-electric, their characteristics leading to more uniform speed and less stop and go situations could still potentially contribute to a reduction in emissions.

The interventions of replacing on-street parking with driving lane, cycle lane and public spaces have shown a better performance in reducing the CO2, NOx, and PM emissions compared to those interventions of removing half of the on-street parking spaces and replacing them with pick-up/drop-off spaces for shared CAVs. This is a consequence of pick-up/drop-off manoeuvres that may generate queue build-up on the road, while vehicles that pick up or drop off passengers lead to increased stop and go situations and emissions. The introduction of automated ride sharing services in the study network showed an increase in emissions under mixed fleet scenarios. The rate of shared trips was found to be a crucial factor in this regard as empty VKT could increase due to empty pick-up trips resulting from low willingness to share.

Literature has indicated promising benefits of GLOSA application on the environmental impacts of transport. Within LEVITATE, since electrification of CAVs was considered, this reduction in emissions with increasing MPR is mainly attributable to this assumption. Additionally, under the GLOSA sub-use case, due to only considering CAVs to be GLOSA equipped, the impact of the system on emissions cannot be directly determined since there is little information on the responses of human drivers to GLOSA instructions. In terms of seeing how GLOSA equipped vehicles caused the changes in network flow which in turn had an effect on emissions, only a marginal reduction was found in the results.

The outcomes of microscopic simulation and the Delphi method for the automated urban shuttle services showed also a positive environmental impact as autonomous public transport and new mobility services can reduce traffic in cities.

For freight transport, CO2 emissions were considered for the freight vehicles for the automated delivery and automated consolidation SUCs. The impact on the overall traffic is small, since the share of freight traffic is low. For the freight vehicles, another primary influencing factor beside electrification is the mileage. Since the consolidation via city-hubs are effectively reducing the mileage by over 55% in our calculations, the potential for reducing emissions is huge, even if the drivetrain is not changed. The baseline results for CO2 emissions of freight vehicles show large reductions (50%) when the share of human-driven vehicles is at 60%- and first-generation automated vehicles is at 40%. Larger reductions of 80% to 100% are achievable when the share of human-driven vehicles drops to 20% and below and second-generation vehicles increase to 100%. This gradual reduction reflects the transition in the microsimulation from a freight vehicle fleet which is 100% human-driven and diesel-fuelled, to a fleet which is 100% autonomous and electric (assumed to be emission-free). In each of the three sub-use cases, a 100% reduction of emissions occurs once electric freight vehicles fully replace conventional vehicles.

Road Safety

Safety is affected in various ways by increasing MPR levels of CAVs and the specific sub-use cases that are investigated in Levitate. The impacts on car-car/truck crashes are estimated using micro-simulation in combination with the Surrogate Safety Assessment Model (SSAM). For all sub-use cases, the baseline scenario, i.e., increasing MPR of CAVs without an additional policy intervention being implemented, results in a decrease in car-car crashes. The magnitude of the decrease, however, differs between sub-use cases. Fatalities among vulnerable road users in crashes with cars are expected to decrease by more than 90% in case of a MPR of CAVs of 100%. Dedicated lanes for CAVs are expected to increase the number of crashes per km travelled compared to the baseline scenario (no dedicated lane) at low and high MPR levels. This can be explained by high traffic volumes in respectively lanes for non-automated vehicles and lanes for automated vehicles. When the vehicle fleets are more equally split, a small benefit can be seen of dedicated lanes when implemented on A-level roads.

The sub-use case focusing on parking price and parking behaviour shows that crash rates might increase at lower MPRs, with 20-40% of the vehicle fleet being automated. This is primarily due to interactions between human-driven vehicles and automated vehicles, which are expected to have different driving styles and capabilities. This increased risk due to mixed traffic is particularly visible in the "drive-around" scenario, where the automated vehicles cause additional congestion on the road—and therefore, additional opportunities for conflicts.

According to the results of the microsimulation, removing or replacing on street parking by other facilities does not seem to have an additional impact on the rate of car-car crashes compared to the baseline scenario in which parking spaces are not removed. The replacement of on-street parking with cycling lanes or public space can be expected to have an impact on VRU accident numbers. The replacement of pick-up and drop-off points could affect pedestrian safety, via unexpected interactions between pedestrians and cyclists or cars.

Automated ride sharing is expected to slightly increase rates of car-car crashes compared to the baseline scenario, although the differences are small and appear to show some random variation. Neither the percentage of demand served nor the willingness of passengers to share trips show a clear relationship with the crash rate. The surrogate safety assessment of GLOSA system showed an improvement in safety (lower crash rate) with the GLOSA implementation at multiple intersections in the test network, particularly at low CAV MPR scenarios, as compared to baseline scenario (without GLOSA) and single intersection implementation.

Regarding automated urban transport, road safety impacts were estimated from the microsimulation studies in Athens. The crash rate of all vehicles in the network improves steadily at higher penetration rates of connected and automated vehicles; when the share of second-generation vehicles is at 20% the crash rate is reduced by 20% and when the share is at 40% the crash rate is reduced by 36%. At larger shares of second-generation vehicles (60-100%) the crash rate of urban transport vehicles is reduced by 50% to 69%. The point-to-point and on demand sub-use cases, as well as the scenarios involving a dedicated shuttle lane or variations in shuttle fleet capacity, had little impact on road safety beyond those effects seen in the baseline. The microsimulation software is limited to the simulation of motor vehicles on the road, and therefore does not simulate interactions involving vulnerable road users (VRUs) such as pedestrians and cyclists. Increasing penetration levels of CAVs in general is expected to decrease fatalities among VRUs by more than 90% in case of 100% CAV penetration. Compared to the baseline scenario, the sub-use cases on automated urban shuttles are not expected to have large additional effects on specifically vulnerable road users. Where larger potential impacts are expected (e.g., on-demand shuttles stopping for boarding/alighting) it was not possible to quantify the impacts on VRU with the available data and simulation methods. Therefore, impacts on VRUs were not quantified for these sub-use cases.

For automated freight transport, the quantitative results for the number of potential crashes are based on microsimulation and Surrogate Safety Assessment Model (SSAM). They indicate consistently that with a higher CAV penetration rate, the number of crashes per vehicle kilometre will decrease significantly when human driven vehicles are fully replaced by CAVs. However, during the transition phase with a balanced mix between manual and automated vehicles, the crashes will rise temporarily compared to the status quo today. Considering the automation of freight vehicles, the automated urban delivery

SUC indicates that automated vans will reduce the number of potential crashes by 3% in average, and in the hub-to-hub automated transport SUC the automated trucks will reduce the number of potential crashes by 8% in average.

Public health

Public health was associated with the changes in active travel, and impact on environment through energy consumption and emissions indicators. A majority of experts' opinion showed a positive impact on public health from increasing CAVs in the baseline scenario. However, some responses indicated a potential deterioration (almost by 11%) of public health from reductions in active travel according to experts. Regarding the CAV dedicated lane scenarios, all prediction curves presented some oscillations depending on AVs market penetration rates. In the long term for 100% CAV market penetration rate, all scenarios will improve public health, which is also explained by their impact on energy efficiency according to experts.

Regarding parking space regulations, as expected, the Delphi results indicated that replacing on-street parking space with public spaces will improve public health the most. On the other hand, replacing on-street parking space with driving lanes will deteriorate public health. A significant decline in public health was foreseen by a majority of the experts under the 'drive around' scenario , reaching up to 25% in the long term which can be explained by its impact on energy efficiency. Whereas the ‘park inside’ and ‘park outside’ scenarios were predicted by most of the experts to improve public health in long-term reaching up to 9%. The 'return to origin’ scenario was indicated to have no effect on public health.

Automated ride sharing services are expected to improve public health by almost 12% at full fleet penetration of CAVs. This can be expected with increasing willingness to share the ride, leading to a reduction in number of personal vehicles on road, which in turn will decrease emissions. It is important to note that such services could negatively impact active travel, as indicated by the SD results in D 6.3 (Sha et al., 2021).

Regarding the impacts of GLOSA system, overall, majority of the experts indicated no effect at all on public health.

For automated urban transport, when penetration rates of automated vehicles reach 80-100% in the baseline scenario, compared to the situation with only human-driven vehicles and no CAVs, an increase of 2-4% is expected in public health.

For automated freight transport, the wider impacts on public health were based on a two round Delphi panel where experts expected an improvement with increasing AV penetration rate. The automated consolidation and hub-to-hub freight transport SUCs are anticipated to generate substantial added improvements in public health (8% to 10%) once human-driven vehicles are below 60%, and to further improve (by up to 18%) once the entire vehicle fleet is automated. The automated delivery sub-use case is expected to generate a more modest improvement in public health, starting at 3% when human-driven vehicles are still at 80% and rising to above 8% once automated vehicles are in the majority.

Accessibility in transport

This impact refers to equality in access to transport and was assessed through determining the degree to which transport services are used by socially disadvantaged and vulnerable groups including people with disabilities (10 points Likert scale). A majority of the responses from experts in the Delphi study suggested that the baseline scenario, the introduction of CAVs with no other intervention will improve accessibility in transport. However, the expectation on degree of improvement varied from 6 to 20%. All city tolling schemes can be expected to negatively impact accessibility in transport while majority of the experts predicted the greatest impact with a static city toll strategy.

Regarding the CAV dedicated lane scenarios, the results present some fluctuations depending on CAVs market penetration rates. The scenario of a CAV dedicated lane on the outermost motorway lane will negatively affect accessibility in transport reaching a maximum reduction of almost 10% for 80% CAVs market penetration rate. It was estimated that under the schemes of dynamically controlled CAV dedicated lane, and the CAV dedicated lane on the outermost motorway lane and A-road, the accessibility to transport will generally improve by almost 6% and 10% respectively, at 60% AVs market penetration rate. In the second round, the majority of the experts moderately agreed with these results.

Experts indicated that replacing on-street parking space with driving lanes or with pickup/drop-off spaces will both positively affect accessibility in transport. Replacing on-street parking space with public spaces will reduce accessibility in transport. Under parking price policies, experts predicted an improvement in accessibility in transport under 'return to origin' parking scenario. However, in all other scenarios a negative impact of parking price policies was observed. The worst impact was foreseen in 'drive around' scenario, with a decrease of around 10%. In this regard, the experts' opinion on automated ride sharing services was that it will improve the equality in access to transport almost from 10 to 22%. Due to implementation of GLOSA system, some experts indicated a general increase in accessibility while half of the participants in the second round showed disagreement and indicated no effect at all due to GLOSA application.

For automated urban transport, when penetration rates of automated vehicles reach 80-100% in the baseline scenario, compared to the situation with only human-driven vehicles and no CAVs, an increase of 19-23% is expected in accessibility in transport.

Commuting distances

Overall, only a small increase in commuting distance was observed with the SD model, with increasing automation under baseline scenario and with implementation of each policy intervention studies in this deliverable, reaching maximum value at full penetration of CAVs. The maximum impact on commuting distances was estimated to be with the inclusion of automated ride sharing services with higher demand and willingness to share (20% demand and 100% willingness to share), as compared to the baseline scenario. This can be expected as such service would provide access and serve customers anywhere to anywhere. In addition, the option to share a ride with others would add to the total distance travelled of that trip. The results indicated that replacing on-street parking with driving lanes would encourage a greater number of vehicles on roads and potentially increase distance travelled. However, the results do not indicate much change in commuting distances due to this policy measure. A similar trend was found with the removal of 50% of the on-street parking spaces.

With parking price policies creating balanced parking behaviours, there was only marginal difference in commuting distances with comparison to the baseline. SD model estimates on road use pricing implementation indicated an increase in commuting distances due to the fact that inner city residents would be subject to road use pricing and might therefore decide to relocate to outer zones.

For automated urban transport, when penetration rates of automated vehicles reach 80-100% in the baseline scenario, compared to the situation with only human-driven vehicles and no CAVs, an increase of 1% is expected in commuting distance while the system dynamics model predicts that last-mile AUSS can slightly reduce the average commuting distance.

Final Comments

It should be noted that policy makers can influence the impacts of CAVs, for example by adopting regulations concerning the conditions that must be met by CAVs to be allowed on public roads and by interventions of which some are analysed as SUCs in LEVITATE.
The knowledge from LEVITATE provides useful insights for policy development and can be used to support future policy-making for smart city transport and traffic.

There are strengths and limitations of the impact assessment approach adopted within LEVITATE, explained in detail in Levitate deliverables D5.5, 6.5, and 7.5; while the aspects of generalisability of results to other cities are presented in the Levitate working paper on Transferability (Sha et al., 2022).

More information

More information on the wider impacts of the various SUCs can be found in:

Roussou, J. et al. (2021). Long-term impacts of cooperative, connected, and automated mobility on urban transport, Deliverable D5. 4 of the H2020 project LEVITATE.

Chaudhry, A. et al. (2021). The long-term impacts of cooperative and automated cars, Deliverable D6.4 of the H2020 project LEVITATE.

Hu, B. et al. (2021). Long term impacts of cooperative, connected and automated mobility on freight transport, Deliverable D7.4 of the H2020 project LEVITATE.

Goldenbeld, C., Gebhard, S., Schermers, G, Nabavi Niaki, M., Mons, C. (2021). Guidelines and recommendations for future policy of automated urban transport, Deliverable D5.5 of the H2020 project LEVITATE.

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Goldenbeld, C., Gebhard, S., Schermers, G., Mons, C and Hu, B. (2021). Guidelines and recommendations for future policy of cooperative and automated freight transport, Deliverable D7.5 of the H2020 project LEVITATE.

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Sha, H. et al. (2021). Medium-term impacts of cooperative, connected, and automated mobility on passenger transport, Deliverable D6.3 of the H2020 project LEVITATE.

Zach, M., Sawas, M., Boghani, H.C., de Zwart, R. (2019). Feasible paths of interventions. Deliverable D4.3 of the H2020 project LEVITATE.