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Assessing the impacts of shared autonomous mobility with M^{3}ICA: A multi-impact, multi-actor, multi-criteria approach

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Abstract

The impacts of connected cooperative autonomous vehicles on society can be significant. We propose a holistic framework that brings together stakeholder assessment with quantitative evaluation of impacts. In this paper, we apply the first part of the framework, and present our findings from a stakeholder workshop within the context of the H2020 SHOW project. 6 groups of stakeholders in the Linköping pilot site participated in a MAMCA workshop and evaluate scenarios of autonomous mobility. Performance scores of each scenario were calculated using the scores and weights assigned to each criteria by their level of importance for each actor group. The findings show a general positive perception of autonomous mobility, with public actors preferring autonomous shared modes, while users and mobility service providers found modes that supported flexible transport to achieve their objectives better.

Keywords: CCAM – Performance indicators; Shared mobility and CCAM; Impact assessment framework; Multi-actor multi-criteria analysis

1. Introduction

Connected cooperative autonomous vehicles (CCAV) have the potential to revolutionize passenger and freight transport, but their impacts on transport networks, society and beyond remain unclear. While literature studying the impacts of CCAV is extensive, it is primarily focused on direct observable impacts, mainly through single-focus simulation studies that rely on assumptions of causality and interconnections between impacts that are difficult to verify (Rashidi et al., 2020). A holistic impact assessment would require the use of multiple individual approaches on each area of interest. Thus, there is a need for a holistic approach that can support multiple impacts of CCAV, as identified for shared urban mobility by Roukouni & Homem de Almeida Correia (2020), with real life demonstration

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as a basis. As part of the EU-funded SHOW project, which involves large scale integration of shared autonomous mobility in the public transport fleet, demand responsive transport and logistics, we have developed a holistic multi-impact, multi-criteria, multi-actor assessment (M³ICA) framework. The methodology proposed combines two different assessment processes: a stakeholder assessment and a data-driven assessment. The former is done by applying the MAMCA methodology, a multi-criteria method in which relevant stakeholders are asked to assign performance scores to different scenarios based on how they achieve the respective objectives of the actors (Macharis et al., 2012). The latter is conducted by evaluating quantitative input, to be collected over a one-year demonstration period in multiple field operation test sites and through concurrent simulations. With this framework, we seek to assess not only the direct effects of shared AVs, but also wider effects on networks and society. In this paper, we present the results of an application of the first stage of the methodology. A MAMCA workshop was organized and conducted in a SHOW pilot site, in which 6 groups of stakeholders participated and provided their assessment of 4 autonomous mobility scenarios. These scenarios reflect the use cases applied in SHOW, under 8 criteria, reflecting the impact areas addressed in the project. In the coming year, similar workshops will be organized across all SHOW pilot sites and they will be complemented with measured data.

2. Methodology

The proposed M³ICA framework combines two different assessment processes: a data-driven assessment, and a stakeholder assessment. The former is conducted by evaluating quantitative input, to be collected over a one year demonstration period in multiple field operation test sites and through concurrent simulations. The latter is done by applying the MAMCA methodology. This multi-criteria method involves organizing workshops in which the relevant stakeholders are asked to assign performance scores to different scenarios based on how they achieve the respective objectives of the actors (Macharis et al., 2012). The M³ICA is conducted over 6 steps (see Figure 1 below), and in this paper, we will present the results of the first part of the framework, the stakeholder assessment using the MAMCA approach (steps 1 and 2).

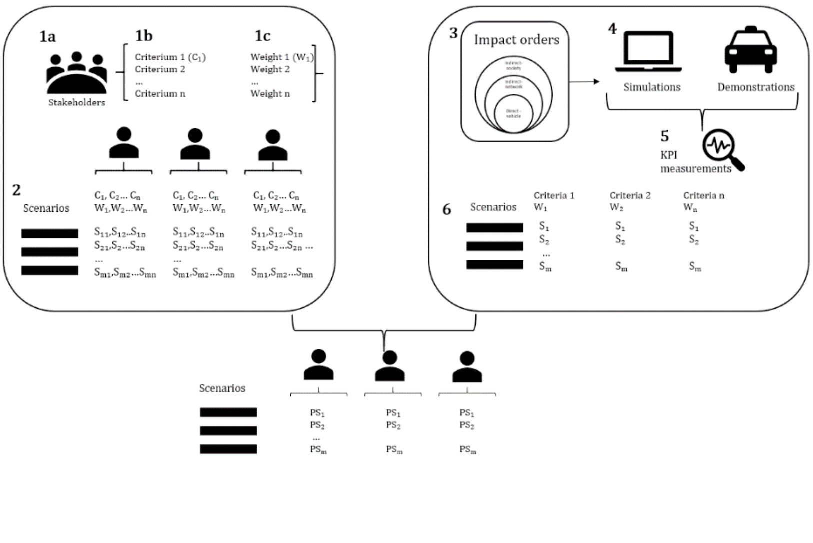

Fig. 1. M³ICA Flowchart

The first step is to determine the stakeholders to be involved in the evaluation process (step 1a. The stakeholder groups that were identified in the context of the SHOW project are:

- Vehicle users (end users, drivers, and remote operator)
- Public interest groups and associations
- Decision-making authorities or regulators
- Operators (e.g., public transport operators, private fleet operators)

- Mobility service providers
- Industry (e.g., AV manufacturers)

The next step is to identify the impact criteria to be evaluated (step 1b), matching the relevant impact areas of interest and the objectives of the stakeholders (Macharis et al., 2012). These impact areas were identified within the SHOW project.

Table 1. Definition of the Impact Criteria

Criteria	Definition	KPIs of Interest
Road Safety	Impact of CCAV fleets on safety of passengers, drivers, and road users in general (pedestrians, cyclists..)	Road accidents, Road conflicts, Instances of illegal overtaking, Traffic Flow
Traffic Efficiency	Performance of CCAV fleets in terms of meeting the travel demand in the transportation system, the network usage, and reliability	Average speed, Acceleration variance, Hard braking events, Number of travelers, Kilometers traveled
Energy Efficiency	Performance of CCAV fleets in terms of consumption of energy (battery usage if electric, fuel if ICE)	Energy use
Environmental Impact	Impact of CCAV fleets on emissions, air quality and noise	CO2, PM, NOx emissions, Noise levels
Societal Impact	Performance of CCAV fleets in terms of uptake from users	Shared mobility rate, Empty vehicle kms, Operative revenues, Operative costs
Employment	Impact of CCAV fleets on mobility related occupations in terms of job creation and losses (or replacement)	Job losses, Job gains
Social Equity	Impact of CCAV fleets on accessibility for people with reduced mobility	Person kms traveled by special groups of citizens (elderly, PRMs, children)
Logistics	Impact of CCAV logistics fleets on freight transport and delivery performance, and acceptance of AV logistics services (delivery robots, freight vehicles) in urban spaces	Ratio of average load, Number of cargo transported, Punctuality of deliveries, Unit cost of delivery, Public acceptance of AVs for urban delivery
User Acceptance	Perception of users of the AV services in terms of reliability, safety, comfort, utility, and travel costs	User reliability perception, User safety perception, Travel comfort, Perceived usefulness, Willingness to pay, Willingness to share a ride

In the second step, the stakeholders score the performance of previously defined scenarios of autonomous services based on the criteria. Specifically, the scenarios reflect the various shared autonomous mobility implementations in the SHOW project in this work. The first scenario is a base business as usual scenario, which can be used as a reference by the stakeholders in the scoring process. Considering it is difficult to imagine future scenarios with a single type of autonomous service, the scenarios are described as a combination of the business-as-usual case with the unique autonomous mobility service.

- **Scenario 0- Business as Usual**: Current traffic system with non-autonomous passenger cars and non-autonomous public transport services. Efficient high capacity PT network with high capillarity and frequency operated by train, metro, tram and bus in dense urban areas.
- **Scenario 1- BAU+ Driverless shuttle for first/last mile:** This scenario assumes public transport remains in operation as business as usual, with the addition of autonomous shared services which act as a feeder service to PT for the first/last mile. In the SHOW pilot sites, these connections include hospital campuses, universities, school, and residential areas. The vehicles follow a fixed route to or from public transport stations with the possibility to implement on-demand stops or fixed stops. The service operates in parallel to high-capacity public transport. Depending on the area, the service operates on a fixed line with fixed stops or can serve as an on-demand service, where the user requests a pick-up at the nearest stop. 1 to 5 shuttles are deployed in pilot sites, with a capacity of around 12 people (subject to Covid-19 restrictions).
- **Scenario 2- BAU+ Door-to-door delivery of persons and goods:** This scenario assumes public transport remains in operation as business as usual, with the addition of a shared, on-demand, point-to-point service with dynamic routing when or where demand is low, using autonomous shuttles. This service is detached from a fixed route or primarily purpose. Passengers can be picked up and dropped off in locations of their choosing (DRT), though it may be possible that these points are fixed and may require a short walk.
- **Scenario 3- BAU+ Mass transit AV services:** This scenario assumes that mass transit AV services replace existing PT (mostly bus) lines with a shared autonomous shuttle or bus. Other PT modes remain unchanged. The bus runs on a fixed route with fixed stops. Passengers wait at the predefined bus stations and are informed for the bus arrival time via their mobile application. The bus stations are also equipped with the bus schedule. The bus

follows the route and stops at each station where passengers are detected. The route of the autonomous shuttles runs between the city center and points of interest for citizens (intercity bus station in Trikala for example, but also hospitals, suburb areas etc.).

- **Scenario 4- Shared robotaxis:** This scenario assumes public transport remains in operation as business as usual, with the addition of robotaxis to the transport landscape. Robotaxis are a point-to-point shared service that operate like regular taxis. Journey reservation is on-demand and the user is picked up at their location. This service is available for private use and sequential sharing. This service connects dense urban city centers to residential areas, or to tourist places of interest.

After a plenary presentation of the criteria, scenarios and the process, each individual stakeholder group goes into a separate breakout room. Based on group discussions, they assign weights to criteria reflecting their relative importance with respect to the objectives of said stakeholders. Using a dedicated online MAMCA tool, they can report their scoring using a slider scale from 1 to 100.

Once they have completed assigning importance weights to criteria, stakeholders are then asked to assign a performance score to each scenario under each criteria based again on discussion in their breakout room. They do so by choosing a score from 1 to 10 reflecting the extent to which a scenario achieves a positive or negative impact in a specific area (criteria). The scores assigned by the stakeholders are aggregated with the weights using the Simple Multi-attribute Ranking Technique (SMART). This approach is based on a simple linear-additive model, as an overall performance score for each scenario is calculated by multiplying the weight of each criteria by the score given by each stakeholder (Barfod and Leleur, 2014).

3. Results

From the SHOW pilot sites, the city of Linköping in Sweden was selected for the first pre-pilot phase workshop. The pilot site operates a first/last mile autonomous shuttle service connecting public transport with a university campus, elderly homes, and a school for children with special needs.

The workshop was conducted on March 25th, 2022, in a hybrid format with 7 participants attending in person and 4 participants virtually. In the specific context of Linköping, industry and public interest groups were not applicable. Instead, landowners and researchers were considered as additional stakeholders, as they were both significantly involved in the pilot site organization. It must be noted that some researchers were used as proxy for vehicle users. As users could not be included in the workshop, researchers have been asked to represent their perspective. As they were involved in acceptance studies and user engagement work with users, researchers are informed representatives. Considering their priorities and objectives, the stakeholders were not assigned all criteria in the assessment.

Table 2 below shows the assigned weights, an empty space means that the criterion was not taken into account for this stakeholder group. Overall, road safety, traffic efficiency and user acceptance are the most consistently highly weighted criteria, with road safety being considered the most important for all applicable stakeholders. Social equity is weighted relatively low for most stakeholders, with only researchers considering it as important as road safety, environmental impact and societal impact. Employment has the lowest importance for most stakeholder groups.

Table 2. Criteria Weights Assigned by Stakeholders

	Vehicle Users	**Public Authorities**	**Mobility Service Providers**	**Public Transport Operators**	**Land Owners**	**Researchers**
Road Safety	0.292	0.186		0.187	0.174	0.157
Traffic Efficiency	0.196	0.157	0.263	0.168	0.139	0.137
Energy Efficiency		0.137	0.241	0.131	0.122	0.059

Environmental Impact	0.12	0.137		0.131	0.174	0.157
Societal Impact	0.062	0.127	0.155	0.15	0.07	0.157
Employment		0.021	0.062	0.112	0.052	0.059
Social Equity	0.052	0.098			0.157	0.157
User Acceptance	0.278	0.137	0.279	0.121	0.113	0.118

The overall result of the workshop shows a generally positive view of the autonomous scenarios. No single scenario is the best performing across all actors. The business-as-usual scenario is scored the lowest for most stakeholders, except for landowners and PTOs, indicating that the autonomous mobility scenarios are positively perceived by the relevant actors. Mass AV transit is highly rated by public transport operators, public authorities, and researchers but only ranks fourth in the vehicle users, landowners, and mobility service providers rating. Shared robotaxis are considered the best performing option by vehicle users and mobility service providers and is well scored by public authorities. However, public transport operators and landowners think it performs the worst out of all scenarios.

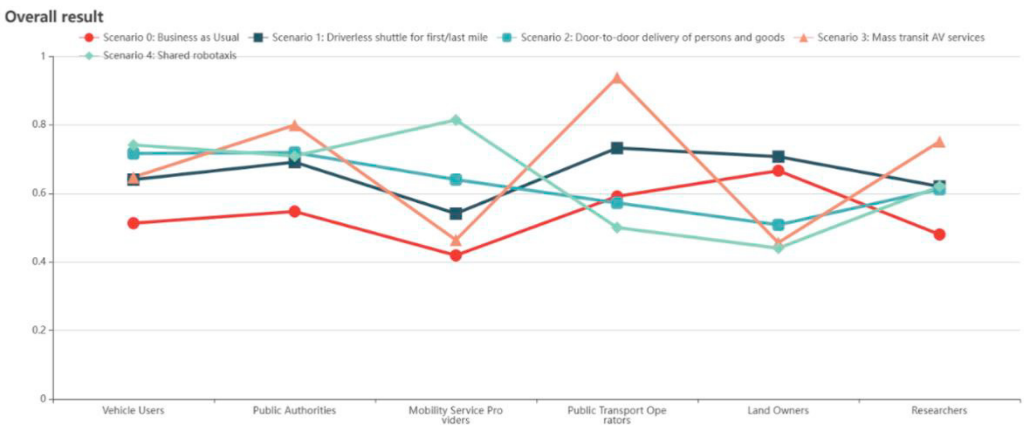

Fig. 2. Overall MAMCA Result

Vehicle users consider road safety, user acceptance, and traffic efficiency to be the most important. Unsurprisingly, the shared robotaxis scenario, which has the highest aggregated score, scores highest in these criteria. In the plenary discussion, representatives of vehicle users mentioned that flexibility in mobility was considered the most important factor in determining how they perceive automation solutions. Thus, their evaluation favored robotaxis and door-to-door delivery, which offer more freedom and flexibility for users in comparison to mass AV transit and the BAU scenario.

Mobility service providers' assessment was comparable, with similar rankings, albeit more significant differences in scores. Similarly to the vehicle users, flexibility for users was considered the most important factor in the assessment. The main objective for mobility service providers is to have the best product for their users, and the most convenient in terms of flexibility, location, options for private transport or limited sharing. Thus, they considered that robotaxis and door-to-door delivery would provide more freedom and comfort in travel, and thus perform best in criteria like user acceptance and societal impact.

The two public organizations were more impartial to mass AV transit, which they considered would achieve their objectives more than the other autonomous mobility services. For public authorities, mass AV transit consistently performs best across the important criteria, like road safety and traffic efficiency. From their perspective, mass AV transit is the closest to existing modes of transport, thus, does not require significant changes in regulations, while other scenarios could bring a more significant disruption to urban transport and subsequent regulatory frameworks. Public transport operators provide a similar assessment, though their preference for traditionally shared options is more pronounced. Across the most important criteria (road safety, traffic efficiency, societal impact), driverless shuttles and mass AV transit score the highest. On the other hand, robotaxis and door-to-door delivery is even scored lower than BAU in most criteria, highlighting that PTOs do not consider private autonomous mobility options to be significant improvements from the status quo. During the discussion, the PTO representatives emphasized that while they do think mobility is about having a mix in available modes, automating shared public transport services is, in their opinion, the preferred path.

4. Conclusions

In this research, we have conducted a stakeholder driven assessment of autonomous mobility scenarios using different criteria. The results highlighted that road safety is considered the most important factors by all stakeholders, often followed by user acceptance, which all stakeholders considered to be critical in the uptake of AVs. Overall, the MAMCA workshop highlighted the positive perception that stakeholders have of autonomous solutions for passenger mobility compared to the business-as-usual scenario, with varying preferences depending on the stakeholders' objectives. Traditionally shared solutions were more positively evaluated by authorities, transport operators and researchers. Stakeholders who considered the perspectives of the end users more, i.e., vehicle users and mobility service providers, found more advantageous scenarios that offer flexibility to users.

The study is, of course, not without its limitations. The stakeholder assessment is in its nature highly subjective and reflects the biases of the participants. While the stakeholder groups represented were many, only 2 individuals per stakeholder were present, thus, the discussions were limited and individual biases were no significantly tempered. Furthermore, in the specific case of vehicle users, we had to use researchers as proxy due to the difficulty of involving the actual users, as the target group in Linkoping was children and elderly with dementia. While researchers were informed representatives, the lack of participation of the actual users in the discussion is a limitation that will be addressed in future workshops. Finally, we could not use quantitative measures from the pilot site, due to delays in the calculation of the KPIs, which has made the process of identifying impacts in concrete terms difficult for the stakeholders. The current application presented in this paper will be further extended with quantitative measurements from field operation tests once they are available, both as part of the data-driven assessment and as supporting material in the stakeholder-driven assessment. Further improvements to the framework include a definition of the integration of survey data (used for user acceptance evaluation) in the data-driven assessment process, in which the challenge is the standardization of the data inputs.

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References

Barfod, M. B., & Leleur, S., 2014. Multi-criteria decision analysis for use in transport decision making.

Macharis, C., Turcksin, L., & Lebeau, K., 2012. Multi actor multi criteria analysis (MAMCA) as a tool to support sustainable decisions: State of use. Decision Support Systems, 54(1), 610–620.

Rashidi, T. H., Najmi, A., Haider, A., Wang, C., & Hosseinzadeh, F., 2020. What we know and do not know about connected and autonomous vehicles. Transportmetrica A: Transport Science, 16(3), 987–1029.

Roukouni, A., & Homem de Almeida Correia, G., 2020. Evaluation Methods for the Impacts of Shared Mobility: Classification and Critical Review. Sustainability, 12(24), 10504.