DIT4TraM

Distributed Intelligence & Technology
for Traffic & Mobility Management

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Contents

Executive Summary

This report constitutes Deliverable 5.1 of DIT4TraM project, which reflects the work carried out under Task 5.1 (Multi-actor fair cooperation scheme analysis and design: review and stakeholder analyses) as part of the WP5 (Fair cooperation schemes for urban mobility management in future multi-actor settings) during the period M1-M12 (September 2021 – August 2022).

After a brief introduction provided in chapter 1, chapter 2 presents a state-of-the-art literature review on centralised, decentralised and distributed systems for achieving efficient cooperation between stakeholders in multi-actor settings. First, the mathematical interpretation of representing competition in urban mobility as a game is discussed and two ways of solving a game between travellers and authorities are introduced; user equilibrium and system optimum. User equilibrium is considered to be a stable state while system optimum is the most efficient state of the network -often in conflict with user equilibrium. Next, the importance of Key Performance Indicators is highlighted in order to steer mobility systems towards more social and environmental-friendly states. To push both users and mobility service providers towards optimal co-acting, it is also essential to study their cooperation and explore authority regulation possibilities. A recent concept that may foster cooperation and help apply new policies is Mobility-as-a-Service (Maas), however, it still requires further analysis.

The review also covers the main modelling assumptions and studies the system's subcomponents that need to be defined before modelling. Even though the considered research papers are similar in the way they formulate optimization problems and in the parameters they use, we notice that their research directions are positioned between two extremities (Figure 1): a) market state and share modelling, and b) operational modelling, that is, matching of passengers and vehicles and their behaviour.

Figure 1. Urban transportation modelling poles

Market modelling is focused on the strategic decisions and long-term competition between mobility services which involves the cost allocation, demand share, and investment decisions. In most cases, models are not dynamic and are characterised by diverse cost variables. The best example of market-oriented studies is Ni et al. (2021). Operational-oriented modelling assesses the competition from the point of view of immediate decisions and profitability. Research is focused on the behaviour and incentives of passengers and vehicles as well as the factors that influence their matching. Operational models are often dynamic. An example of such work is Ramezani & Nourinejad (2018). It is noteworthy that many studies are balancing between those two extremities.

Later on, the Key Performance Indicators (KPIs) that are often considered in urban transport research studies are described, as well as the parameters that influence KPI values. It is found that there are not many studies that assess the influence of competition on the defined KPIs. It is found that research is mainly focused on the influence of competition on fares, costs, demand rates, fleet, and other modelling parameters but not on the externalities of competition on the overall system state and environment.

Finally, the review is concluded with the study of regulations, focusing on the competition regulations for ride-sourcing vehicles. Fleet size cap, minimum driver wage, and congestion charge are some of the most popular regulations, however, the list of solution policies is limited, and we find that their influence on the competition externalities is not covered enough in the literature. Additionally, many of them consider the competition of ride-sourcing vehicles with traditional travel modes such as public transport and taxi instead of studying the inner concurrence in the ride-sourcing market. Thus, it is necessary not only to deeply study the existing competition regulations but also to develop new approaches. In addition, the examined competitive market policies aim to regulate each company's position in the market instead of mitigating the negative impact of competition. The only factors that are often considered while evaluating the regulations of a competitive market are social welfare and consumer surplus.

In contrast with competition, various studies analyse the general policies imposed to control ride-sourcing operations and their impact on traffic state. According to (Ke, Li, et al., 2021), none of the authority regulations in highly congested systems lead to Pareto-efficient results. The reason is that private vehicles have the most significant impact on congestion, so by simply regulating ride-sourcing services, the impact on the traffic state will not be significant. The authors suggest that authorities should adjust the policies according to each city's traffic situation. For example, they recommend using the fleet size cap and/or regulating the minimum utilisation rate for ride-sourcing services in cities with severe congestion. At the same time, in non-congested suburbs, it is possible to increase drivers' and consumers' surplus by encouraging companies to engage more drivers. The reason is that the optimal fleet size and driver wage are higher at social optimum than at monopoly optimum in those areas. It is noteworthy that in systems with moderate and high traffic, the application of policies toward ride-sourcing services should be accompanied by regulations for private vehicles.

Chapter 3 introduces a relevant survey and presents its findings. The scope of the survey is to complement the literature review in order to gain better insights regarding the organisational, financial and legal aspects of the conflicting interests between mobility stakeholders, understand their expectations and the current technological and organisational processes needed to improve cooperation. This way, we can identify the instruments that would, through incentives or regulations, boost cooperation between the different mobility stakeholders and favour attaining a collective optimum (social and/or environmental). Since we are more interested in studying the interactions between the mobility stakeholders that can directly affect the transport system, we prioritise public and private operators, service providers, small and medium-sized enterprises around mobility as well as public authorities.

Questions addressed to public organizations and private sector mobility companies revolved around the following dimensions:

- How has competition influenced organisations and what was the impact on the overall system?
- Are organisations willing to cooperate with others to improve system performance?
- What could be the possible fields of cooperation?
- Under which conditions would the different organisations be willing to participate in collaborations?
- Are there regulatory drawbacks or unfair practices in today's market?
- Are regulations needed to foster collaboration between transport operators?
- What are the concerns regarding data exchange?
- What would be the impact of permit, pricing, prioritisation or resources sharing schemes in the different organisations?
- What benefits would motivate the different organisations to participate in the mentioned schemes?
- Would decentralised, distributed or centralised approaches appeal more to the different organisations?

The questions addressed to the representatives of authorities on the other hand, were mainly focused on their willingness to get involved in different parts of the cooperation between mobility stakeholders. More specifically we assessed their interest in:

- Facilitating the cooperation between public and/or private mobility providers
- Becoming a data intermediary between the different providers
- Developing and operating an integrated information and ticketing platform
- Investing in infrastructure needed to support cooperation between mobility providers
- Promoting private services between residences and public transport stations

- Regulating private vehicles and mobility companies by imposing different schemes
- Providing subsidies to mobility companies
- Exploring new policies

The analysis of the results of this survey, presented in sections 3.3.1 and 3.3.2, showed some interesting takeaways about the differences in the operation and motivation behind private and public organizations. As expected, it became clear that public organizations are more interested in socio-political implications of mobility issues while private ones are mainly concerned with profit and their financial well-being. Therefore, the respective incentives could lead these organizations to cooperate with each other. The cooperation schemes that emerged as the most likely are those based on integrated transport services, resources sharing and data exchange, although the unrestricted availability of data seems to be an issue for some private companies that fear competition. In any case most stakeholders believe that overall regulations are necessary to foster collaborations between transport operators. Authorities however, do not appear generally willing to take on the burden of initiatives aiming to improve collaborations amongst mobility actors. They only keep a positive attitude towards the possibility of becoming a data intermediary between different mobility providers or investing in infrastructure. In general, they prefer regulations that do not interfere with commercial activities, which is why they also appear more willing to regulate the use of private vehicles.

1 Introduction

1.1 General

One of the most important aspects of any city is the quality of its transportation system. Several stakeholders influence the organisation and development of the urban mobility network; the most important of them being mobility service providers, passengers, and local authorities. Each party behaves according to its interests and tries to fulfil different objectives. Mobility service providers and operators try to satisfy their budget constraints and maximise profit, while the passengers are usually interested in reaching their destination as quickly as possible with the least cost and a reasonable quality level. At the same time, public authorities aim to provide an efficient transport system to the population while meeting social and environmental objectives by imposing, when necessary, regulations on other stakeholders.

A stable state of the system when none of the actors has any incentive to change their decision is called Nash equilibrium (Chen, 2022). Unfortunately, as each participant usually acts selfishly and makes decisions based on immediate profitability, the equilibrium is not the optimal state for the entire transportation system. The state of the overall network often becomes even worse due to competition between mobility service providers. An example is the competition of ride-sourcing services Uber and Lyft in the USA, where companies increase their operating fleet to reduce customer waiting times (Gindrat, 2021). This situation negatively influences traffic congestion and CO2 emissions as many vehicles move idly for significantly long time periods. In addition, ride-sourcing companies can reduce their prices for passengers in the short term to compete with public transport, increasing environmental concerns. After the appearance of both Uber and Lyft in the US market, ride-sourcing services became a public transportation substitute instead of being a public transportation complement, at least in urban areas (Sadowsky & Nelson, 2017).

While healthy competition can contribute to increasing the quality of services provided to end-users, the conflicting interests of the multiple actors block the overall system from unlocking its full potential network-wise (Butler et al., 2021; Zardini et al., 2021). Cities need to adapt and find solutions to integrate these new mobility services in an efficient and sustainable way while ensuring fairness and equity for all (Litman, 2017). The emergence of novel Connected Cooperative and Automated Mobility (CCAM) services adds even more complexity to the transport system, which increases the need, as well as the expected benefit, for coordination and cooperation (Gonzalez-Feliu et al., 2018; Karlsson et al., 2020; Smith & Hensher, 2020).

1.2 Scope of the Deliverable

This report presents the outputs of Task 5.1 that aims to identify the most critical situations when stakeholders perceive conflicting interests with each other, better understand their expectations, and the current technological and organisational (including communications) processes used to improve cooperation. The work is the first part of WP5 (Fair cooperation schemes for urban mobility management in future multi-actor settings) that investigates and develops possible cooperation schemes between different mobility network actors. These schemes aim to tackle suboptimal system operations caused by selfish competition of stakeholders while approaching a collective social and environmental optimum.

Besides, the addressed issues include fair competition, complementarity between different transportation modes, and long-term system adaptation. As for pricing strategies, the application of credit and permit schemes to mobility operators is covered. The objectives of WP5 comprise as well the assessment of decentralised, distributed, and centralised cooperation schemes. We focus on decentralised and distributed approaches while comparing them to the centralised. All this contributes to the development of a sustainable urban mobility network.

1.3 Methodology

To address the objectives of T5.1 this report comprises two stages; The first stage is a critical assessment of the state of the art, where we delve into the main concepts and specifications needed to better understand the problem of competition and cooperation in urban mobility management. Then, we explore the modelling framework together with its structural and characteristics analysis. Afterward, we provide the test cases where competition has already been identified as an issue. We also cover the solutions that were implemented to improve the drawbacks of competition and archive cooperation. In the end, we discuss the identified research gaps and propose directions for the following WP5 studies. In the second stage, we conduct a survey addressed to representatives from public and private operators, service providers, Small and Medium sized Enterprises (SMEs) and authorities from countries of the European Union, namely France, the Netherlands and Greece, in order to supplement the review in identifying the objectives and goals of the different mobility actors, and to detect the most critical factors that affect cooperation between them.

1.4 Links with other Work Packages

Task 5.1 includes reported impacts on key performance indicators, in relation with WP8 (Assessment methodology and Market Analysis), theory, and modelling. The stakeholder Interviews used to complement the literature review were performed in collaboration with Task 6.1 (DIT4TraM system stakeholders: engagement, consultation and co-creation) and 6.2 (DIT4TraM system use cases and requirements).

1.5 Structure of the Deliverable

Chapter 2 presents a thorough literature review on the concepts and methods around cooperation in multi-actor settings. Chapter 3 introduces the survey design and presents its findings. Finally, chapter 4 includes the conclusions drawn from the analysis of the literature and the results of the research.

2 Fair Cooperation Schemes: concepts and methods

2.1 Problem formulation

The urban mobility management problem is commonly approached by dividing the entire system into smaller sub-parts of only one mobility provider/operator. Such an approach makes the evaluation of the overall functionality and efficiency of the transportation network harder, as the interaction of the main stakeholders is not taken into account. Additionally, the integration of all the sub-problems is crucial to study their influence on each other's operations and the entire system. Each actor is focused on reaching their own objectives, which are usually in conflict with the goals of other stakeholders. In this case, we are talking about **competition**.

Primarily, the competition serves as a prevention of market monopoly (Ma et al., 2018). However, the absence of regulations may have a negative impact. For example, the competition of Uber and Lyft makes those companies hire more and more drivers, which leads to the decrease of driver's average earnings (Jalloh, 2021). In China, the lack of policies caused unhealthy competition between the ride-sourcing companies, leading to urban congestion and high emissions (Sun et al., 2019).

It is noteworthy that competition is possible not only between mobility operators, but also between travellers, operators, and authorities, both inside each group and between the actors of different groups. Hollander & Prashker (2006) explain competition in transport analysis from a mathematical point of view, which is summarised as follows. Competition is defined as a game, the outcome of which can be found by calculating the resulting equilibrium state point. To determine a game, we need to name the players, their alternative strategies, and their objectives. Games can be of different nature: non-cooperative or cooperative, zero-sum, monopoly, pure or mixed strategies, symmetrical or hierarchical relations between players, etc. Depending on those characteristics, the found solution can be different types of equilibrium: e.g., Nash, Stackelberg, or Cournot equilibrium. Sun et al. (2019) considered the competition between the government and ride-sourcing platforms as the Evolutionary Game Model. Each party can use two strategies: "strict regulation" and "loose regulation" for the government and "scale expansion" and "service promotion" for ride-sourcing companies. The behaviour of actors is based on "limited rationality" while equilibrium is reached through the simulation of several games.

The **user (player) equilibrium** is certainly the closest to what can be observed in transportation systems without enforcing any regulations or transport management strategies. Usually, it is used in games between system players or stakeholders while some constraints or rules are applied. An example of constraint can be a limited throughput of roads. A comprehensible explanation of user equilibrium is presented by Sheffi (1985). Given a graph of the transportation network, where the performance of each link is changing over time according to its loading, each traveller wants to reach their destination from an origin while following a common objective, such as minimising travel time. This problem is well-known as the traffic assignment problem. The goal is to reach a stable system state where no traveller can improve their objective by choosing another route. The previous statement is the user equilibrium condition. This state does not mean that all travellers use the potentially shortest path as the throughput of each path decreases inversely proportionally to its loading. Thus, the initially shortest path might not be the quickest anymore with the given conditions.

According to Hollander & Prashker (2006), all the games between authorities and travellers lead to the authorities trying to reach the system optimum while the travellers seek user equilibrium. It is commonly considered that the authorities make their move first, and the travellers respond afterward. Each constraint imposed by the authority changes the user equilibrium, leading to a compromise between the actors. In such games, the mobility operators can be considered as authorities whose objective is to maximise their own profit.

The next question to address is the **system optimum** and why it might conflict with the user equilibrium. Taking the already presented problem from Sheffi (1985) that helps explain the user equilibrium, we can see that each traveller minimises their own travel time. System optimum implies that the objective function of this problem is to minimise the total travel time of all users in the network while meeting the flow conservation constraints. In most cases, the system optimum is not equal to the user equilibrium (even though in some exceptional situations, it can be). Therefore, the system optimum is not a stable state from the user perspective as travellers may unilaterally change their routes to increase their individual utility, e.g., decrease their personal travel time. However, the system optimum is often used as a benchmark as it shows the highest efficiency of the system.

It is important to remember that one of the goals of WP5 is a transition to sustainable urban mobility. According to Ortúzar (2019), the word "sustainable" is based on three pillars: social inclusion, economic development, and environmental balance. Besides the system optimum, another concept that can contribute to sustainable mobility development is, what we call, the **collective** (social and environmental) **optimum**. Social optimization means making urban mobility services more accessible to people, both physically and economically, and also making an accent on the availability of sustainable transport means, such as public transport, ride-pooling, bicycle, walking, etc. An example of social optimization is providing first/last-mile assistance to facilitate reaching public transport stops from remote households. Environmental optimization implies mitigating the harmful influence of transportation on the environment, e.g., decrease in air pollution levels, rational usage and sharing of resources, etc. It is noteworthy that the collective optimum implicitly involves financial fairness and optimization by reducing the expenses on resources, introducing subsidies, putting lower bound on drivers' wages, and many others.

Theoretically, both the system and collective optimum can be approached by introducing **cooperation** and/or **authority regulation**. The work of Wefering et al. (2013) considers the importance of both horizontal and vertical cooperation and exchange. Together with the involvement of stakeholders, it can help reach sustainable urban mobility. In Georgiadis et al. (2020), the authors raise the question of the significance of cooperation between different modes of public transport. They study the co-influence of buses and trains and conclude that, unfortunately, those modes of transport rather coexist than cooperate. One of the possible reasons might be the absence of coordination and service design integration. Currently, the most promising concept that favours and boosts cooperation is called Mobility-as-a-Service (MaaS) and proposes different levels of integration (Kamargianni et al., 2016). However, it should be noted that the benefits from MaaS look more obvious from the traveller's than from the operator's point of view, because of concerns related to losing direct connections to their customer. MaaS is presented in detail later in this chapter.

As one of the main threats for urban mobility sustainability is the high level of congestion, to tackle this problem, Ortúzar (2019) proposes using authority regulations and evaluates policies such as vehicle restrictions and road pricing. For example, one of the existing vehicle restriction strategies is licence plate rationing. The concept of road pricing is based on the extra charges that are imposed on car drivers while using a road. The fee can depend on the time of day or route and represents the marginal road usage cost. In return, the authority maintains high-quality public transport services, thanks to the profit from charges. However, such policies apply not only to private car users but also to transportation network companies (TNCs). Among the main reasons are the high contribution of ride-sourcing vehicles to urban congestion and unfair treatment of employees. The examples of the most mentioned in the literature regulations are lower bounds of drivers' wages (Li et al., 2019), an upper limit on the total number of drivers or vehicles (Beer et al., 2017; Li et al., 2019), a per-trip congestion surcharge (Li et al., 2019; Li, Poolla, et al., 2021; Li, Yang, et al., 2021), per vehicle operating hour congestion surcharge (Li, Poolla, et al., 2021), a charge on entering congestion area (Li, Yang, et al., 2021), a charge on entering or exiting congestion area (Li, Yang, et al., 2021). It is noteworthy that authorities' regulations are not necessarily a type of "punishment" but, on the contrary, can be advantageous for private companies. For instance, the government can provide subsidies to influence the operations of a mobility provider (Brown et al., 2021; Zhu, Ke, et al., 2021) or promote using e-vehicles (Mo et al., 2020) to reach system and collective optimum without reducing providers' profit.

As it was mentioned before, the most recent concept that fosters cooperation between mobility providers is Mobility-as-a-Service (MaaS). According to Utriainen & Pöllänen (2018), MaaS is defined as a concept that combines the subscription for several transport services into one interface. This favours seamless trips when different transport means are used, with only one application to manage the subscription. Thanks to MaaS, there is no need to possess several travel cards as the customer has only one account where all mobility modes are aggregated and can be purchased with a single payment. The idea of MaaS is to provide a service to a user based on their needs rather than providing transport means (Kamargianni et al., 2016). Ideally, the MaaS system should integrate the following elements: ticket and payment system (when one purchased subscription gives access to several transport modes), mobility package (pay for a specific combination of mobility services), and ICT (information and communications technology – aggregation of information about all available transport modes) (Kamargianni et al., 2016). However, the full integration of all those elements is still rare. This is partly due to social barriers, such as network users' heavy reliance on private vehicles, but also to supply-side barriers stemming from a lack of public-private collaboration, a lack of shared vision, and low levels of business support (Butler et al., 2021; Karlsson et al., 2020). Besides, mobility stakeholders often have conflicting objectives; public transport agencies tend to minimize costs while meeting tender requirements, public authorities seek to optimize social objectives, and private companies focus on economic sustainability and profit. Overcoming these barriers requires an environment of trust in which all business partners can expect neutrality, independence, fairness, and an integrator stable enough to stay for a long time (UITP, 2019).

Utriainen & Pöllänen (2018), state that the target population group of MaaS is private car users. One of the goals is to motivate those people to switch to more sustainable transport modes. MaaS also contributes to flexibility and inclusion as disabled passengers can use ride-sourcing at better rates instead of less convenient public transport. However, MaaS requires local authority regulation to ensure that the overall system meets social objectives and KPIs, in particular those related to sustainability. The administration entity needs to monitor the operations of the service-oriented system to guarantee the fairness of user treatment and operators' cooperation. Thus, it can play the role of the upper-level MaaS organiser and be in charge of services collaboration. Another option is having a private company being the MaaS operator. In both cases, MaaS introduces a centralised layer in the system.

Pandey et al. (2019) shows that MaaS can be a communication bridge between mobility providers to promote their cooperation. In this case, the cooperation scheme is either centralised or distributed depending on the chosen system architecture and possible degrees of information exchange. E.g., companies can decide to share information such as the location of their vehicles partly.

In past years, there were several attempts to deploy MaaS pilots in European cities (Hirschhorn et al., 2019; Utriainen & Pöllänen, 2018). All of them had different levels of services integration and authority governance. The study of (Hirschhorn et al., 2019) covered pilots in Amsterdam, Birmingham, and Helsinki. For example, one of the pilots MaaS projects in Amsterdam aims to increase the connectivity of public transport with other mobility options, e.g., bike and car-sharing. Another project in the Amsterdam business district is oriented toward reducing congestion. The goal of the pilot in Birmingham was to increase public transport utilisation and improve the general economic environment. The MaaS project in Helsinki was meant to support sustainability and increase the technological level of mobility solutions. However, we need to bear in mind that due to the concept's novelty, its effect on the overall mobility system is poorly studied.

2.2 Specifications of fair cooperation schemes

2.2.1 Objectives and Key Performance Indicators

The main objective of introducing cooperation and regulations in mobility networks is to reduce the negative externalities of transportation that influence both the natural and social environment. The issue is that the relation between equilibriums and the different types of competition – positive or negative from a social and/or ecological point of view- is not always clear. Some common key performance indicators (KPIs), that are also introduced in the DIT4TraM proposal and are often used to evaluate new such schemes are seen in Table 1.

Table 1. The most commonly used KPIs per category of urban transportation components

System network	Environment	Passengers
% congestion reduction	% congestion reduction	% total travel time change
overall system resilience	% total private cars tailpipe emissions (CO, NOx, CO2) change	% total passenger waiting time change
overall system efficiency	% energy consumption (kWh) change	cost per km
overall system sustainability	% fuel consumption (mpg) change	% total time spent travelling change

daily mode shift (system)		Passenger surplus
% average change towards better system optimum (per week)		
% change in ride-sharing percentage		
cost per km		
% change network efficiency		
% change network sustainability		
vehicle kilometres travelled		
vehicle hours travelled		
% response time to event change		
Stakeholder satisfaction	**Cooperation**	**MaaS**
Users' satisfaction	# integrated modes	# integrated modes
Operators' satisfaction	# services integrated	# services integrated
Authorities' satisfaction	# decentralised schemes integrated	# of data sources integrated
Industry satisfaction	# stakeholders / systems / services arbitrated	# components integrated
Passenger surplus	# components (systems / services) arbitrated	# of applications integrated
Driver surplus	# of data sources integrated	
	% of market share	

As shown in Table 1, multiple groups of KPIs are arbitrated to assess the effect of new operating schemes and equilibria on different aspects related to urban transportation. The first group includes those KPIs that help examine the impact on general system characteristics: congestion rate, robustness, efficiency, and sustainability. The second group evaluates environmental externalities, such as the level of congestion, emissions, and energy consumption. As the most important actor in urban mobility is the user, the third category of KPIs addresses the changes in passengers' experience: waiting time, travel time, and travel cost. The fourth class evaluates the equality and satisfaction from the changes of all mobility system stakeholders. The last two groups of indicators are similar. However, although they have many common KPIs, the fifth category treats cooperation from the conceptual side, while the sixth is an applied cooperation solution. Thus, the fifth "Cooperation" group includes indicators of the number of integrated transport modes, services, schemes, data sources, and participating stakeholders. The "MaaS" group is more digital-oriented and includes indicators of the number of integrated modes, services, components, data sources, and applications.

It is noteworthy that some groups have common or interrelated KPIs: e.g., congestion reduction indicator of system network is also connected to the assessment of the environmental impact (emissions rate). At the same time, such KPI as "cost per kilometre" can express the operational cost for a mobility provider to cover one kilometre of the network but also the price for a passenger to pay per one kilometre of travelling.

Moreover, some social objectives (e.g., accessibility) are more difficult to measure with explicit KPIs. However, they can be evaluated indirectly using presented quantitative KPIs. For instance, if more transport modes participated in integration and cooperation, more diverse choices with lower prices for passengers would appear, which is related to accessibility.

2.2.2 Cooperation schemes

Several cooperation schemes can be applied to urban mobility management. This study examines the next ones: centralised, decentralised, and distributed. They are defined as follows.

The centralised approach implies a common coordinating, decision-making, and control entity. For instance, in Pandey et al. (2019), a MaaS system plays the role of this agent. It collects the demand requests from passengers and the vehicle-request cost matrices from mobility providers. Based on this data, the system assigns vehicles to customers. This scheme requires that companies share private and often sensitive information with the central unit. However, it does not necessarily mean that this information is available for their competitors.

This scheme is capable of providing the global optimal solution (Chow & Sha, 2016). However, it requires much time and computational effort, and the complexity increases drastically with the number of players and network size (Chow & Sha, 2016; Demazeau & Müller, 1990). At the same time, some studies deny this issue as the calculations depend on the server characteristics and can be boosted with parallel processing (Pandey et al., 2019; Zambrano-Martinez et al., 2019). Another problem is that mobility operators can provide false information to manipulate the system in their favour (Pandey et al., 2019). The centralised scheme is also vulnerable to hacking. All the cyberattacks are directed to one target as the failure of the central control unit will crash the whole cooperation system (Logota et al., 2014).

The **decentralised** cooperation scheme assumes several players that act independently and make autonomous decisions but follow a common objective, e.g., sustainability. They can also exchange information and support each other (Hafteck, 2003; Xu et al., 2014). Nevertheless, none of the agents have full information about the network and the complete state of negotiation (Demazeau & Müller, 1990). This means that the global optimum is unlikely to be reached, but the solution can still be feasible and locally optimal if each agent plays rationally. The absence of complete information also means lower computational complexity. Decentralised cooperation has considerable similarity with swarm intelligence (e.g., bee- and ant-colony optimization algorithms) (Kennedy III et al., 2015) and with Multi-Agent Reinforcement Learning (Michailidis et al., 2020) subject to each agent exchanging information with the immediate neighbours.

According to (Hongler et al., 2010), decentralised systems have some advantages compared with centralised. Real-world conditions, are often described by an environment of non-linear relationships with a significant number of parameters and decision variables, where unpredictable interruptions can bring uncertainty. This questions the efficiency and relevance of centralised planning and control. On the other hand, in decentralised management, each agent has access only to local information and, by acting autonomously while communicating with neighbours, may follow a global behaviour. This usually still requires regulations to be implemented as even with information from others or by knowing what would be at the collective level, some players may be reluctant to comply. Under those conditions, the decentralised scheme may perform better than the centralised one.

Another scheme that is used in cooperation is called **distributed**. In the distributed system, every agent performs operations and makes its own decisions. Thus, the global data and operations are divided equally among the agents which play the role of processing centres. However, unlike the decentralised system, the agents may either exchange information with each other regardless of their position in the network or transmit their decisions to the common coordinator centre, which aggregates the data and provides the general result (Antonenko, 2022). The characteristics of decentralised and distributed networks are often confused in the scientific literature. It is noteworthy that the agents cannot access the complete network information in decentralised systems, while in the distributed, the nodes may have this feature (Antonenko, 2022).

A comparison of centralised and distributed control systems was considered in (Monteil et al., 2012). This study examined two cooperation schemes of vehicles to reduce the level of congestion. In the centralised one, all the vehicles at the considered road segment can communicate with the unique traffic management centre, e.g., with the Road Side Unit (RSU), that decides the behaviour of vehicles to prevent congestion. In the distributed system, the vehicles are able to communicate with each other to adjust the personal speed and optionally can connect to the general management centre.

Table 2 summarises the advantages (+) and disadvantages (-) of different cooperation schemes (Antonenko, 2022; Hooda, 2018; Monteil et al., 2012).

Table 2. Advantages and disadvantages of cooperation schemes

	+	-
Centralised	• Provides global optimum; • Structural simplicity; • Quick and easy system update;	• High dependence on the central node; • Difficult central node maintenance; • System vulnerability due to cyberattacks; • High computational complexity; • Limited scalability;
Decentralised	• Minimised performance bottlenecks; • Low computational complexity; • More autonomy and resource control; • Cyberattack and system failure prone; • Easily expanded; • Foster anonymity;	• Difficult global network regulation and coordination (in particular considering systems with conflicting objectives); • Does not guarantee the finding of global optimum; • Lack of complete network information for each agent; • Difficult tracking of node failure;
Distributed	• Low latency; • Secure; • Transparent; • Scalability;	• Problematic consensus reaching; • Complex design and building; • Possible central authority control;

2.3 System modelling

This section covers the representation of subcomponents of the modelling framework, such as the expression of demand and supply, network settings, travel parameters, matching function, the behaviour of agents, etc. For the purposes of this work, it is essential to develop models to assess the control and regulation policies we want to test, as well as to present the state of the art about modelling frameworks considering multiple operators serving the same potential demand.

In this work, we refer to ride-sourcing, ride-hailing, e-hailing, and TNC (transportation network company) as the same service provided by companies like Uber or Lyft where a customer can order a car with a driver via an application to be brought to a destination without sharing the ride with other customers. For the sake of simplicity, in this study, we use only the term "ride-sourcing".

The terms ride-sharing, ride-pooling, and car-pooling refer to the same kind of service, but the ride can be shared with other users, and therefore a detour is possible. In this study, we choose the term "ride-sharing".

By "taxi", we refer to the service where a car can be hailed directly from the street without being ordered via an application.

2.3.1 Network equilibrium in multi-actor settings

Many studies embrace the modelling of network equilibrium in the multi-actor environment of urban mobility (Ke et al., 2020). Most of the time, the following groups of actors are included:

- Mobility companies
- Passengers
- Drivers hired by mobility providers
- Private vehicles
- Local public authorities

Behaviour modelling of all the actors simultaneously is challenging and increases the complexity of the problem and often requires simplification. Thus, in most works, the authors consider mobility companies and passengers plus certain actors from the rest of the given list based on the research objectives. Depending on the modelling framework, private vehicles can play a role of a possible transportation mode of passengers or be an autonomous actor that influences the network's speed and congestion. Additionally, the local authorities are not usually represented as independent actors but rather as constraints imposed on other actors.

Given the definition of user equilibrium from the previous sections, we can define the network equilibrium as a stable state of the system where no actor has an incentive to unilaterally change any of their decisions regarding, for example, transport mode, route, ticket cost, or staff wages. According to Nourinejad & Ramezani (2020), the study of equilibrium is relevant for strategic planning. At the same time, the modelling of non-equilibrium situations is important for operational decisions when the system's stability is interrupted due to abrupt changes or when the system experiences significant variation within a short time period. As our work considers long-term planning, the main focus is network equilibrium.

2.3.2 Network modelling

2.3.2.1 Static and dynamic models

In terms of representation of changes in market state over a time horizon, the model can be static or dynamic. The static model considers that all the parameters of the system are constant. It represents either a general stable state of the system (steady-state) or a state of the system at a particular moment of time. It might be used in strategic market planning. Static models in multi-actor settings were used in (Ke, Zhu, et al., 2021; Ni et al., 2021; Zhu et al., 2020; Zhu, Xu, et al., 2021).

The dynamic models are more accurate as they consider changes in the system over a time period. They also provide a more realistic description of the congestion propagation over the network. The studies that used dynamic models in their transportation multi-actor modelling are (Guo & Huang, 2022; Pi et al., 2019; Ramezani & Nourinejad, 2018). There are two levels of dynamic transportation modelling: microscopic and macroscopic, and they are described below.

2.3.2.2 Classical dynamic models: microscopic and macroscopic

The distinction between microscopic and macroscopic models is based on the representation accuracy of each particular actor. Microscopic type of models is a more detailed multi-agent system, whose goal is to simulate and follow the actions of individual vehicles and passengers that participate in the system. Thus, one can track the position of each vehicle or passenger, their status, waiting time, and driven distance. The microscopic model is the closest to reality as each vehicle is represented.

Macroscopic type of models does not consider individual agents but rather flows in the network. Based on (Nourinejad & Ramezani, 2020), the macroscopic model represents the transportation market and its dynamics. It also shows the supply and demand interaction. This type of model is composed of conservation equations for links and nodes. The equations can be transformed into dynamic constraints when formulating optimization problems.

2.3.2.3 New urban dynamic models

Macroscopic models are more scalable for large-scale applications but they still require a detailed representation of the network in particular at the intersections' level. Microscopic models can also be used as an alternative option to find equilibrium or solve optimization problems at a large urban scale. A new and aggregated modelling framework has been proposed and developed over the past decades. It is inspired by the concept of the MFD (Macroscopic Fundamental Diagram) which describes the traffic states at a region's level. This framework is appealing as it is dynamic, can keep track of individual trips when using the trip-based formulation, while using a simplified representation of the network and traffic dynamics. In a nutshell, all current vehicles in the network drive at the same mean speed at the same time (given by the MFD) depending on their types. Such a representation has been proven accurate when linking regional traffic states (Mariotte et al., 2020). Below we present several types of MFD.

a) Accumulation-based. The key idea is that an area of the transportation system (reservoir) can be described by the number of moving vehicles at time t, which is called accumulation $n(t)$. The accumulation is a state variable, and all other variables are functions of the accumulation. An important variable that depends on accumulation is the production $P(n)$ with units (veh*m/s), which means the distance run by all moving vehicles per time unit. The speed is defined as $V(n) = \frac{P(n)}{n(t)}$, and the outflow as $O(n) = \frac{P(n)}{L}$, where L is a trip length that is the same for all the travellers (Mariotte, 2018).

b) Trip-based. On the contrary to accumulation-based MFD where vehicles in the same regions are considered collectively, the trip-based approach individualises every single trip. This permits to consider individual trip characteristics such as heterogeneous trip length. All vehicles in the same region at the same time still experience the same mean speed. So, the relation between the trip length of vehicle i and its travel time T_i is $L_i = \int_t^{t+T_i} V(s)ds$ (Mariotte, 2018).

In conclusion, we can say that microscopic and macroscopic dynamic models are computationally expensive so the researchers usually prefer using static or MFD-based models.

2.3.3 Demand and supply

To be able to model a multi-actor transportation network, it is necessary to decide how the main modelling components are represented. As there are not many relevant studies that exploit multi-actor settings, we occasionally refer to works where only one transportation operator is considered.

2.3.3.1 Network and demand representation

The network and demand representations are explicitly interrelated. The most intuitive way to represent a transportation network is a graph or grid with a set of links and nodes. In this case, the demand can be given as a set or matrix of origin-destination (OD) pairs. This demand representation is easily associated with the graph structure of the network, where the path between each origin and destination consists of several links (Algaba et al., 2019).

However, the network is often represented in an aggregated manner without considering its detailed structure. Optionally, it can contain a few aggregated zones of origins and destinations. In this case, demand can be given as a set of those zone pairs (Ni et al., 2021; Zhu et al., 2020) whose values can depend on time if the model is dynamic (Ramezani & Nourinejad, 2018).

Another way to define the demand in the aggregated network is via a function. For example, it can be a function of the generalised cost and the waiting time (Ke et al., 2020; Ke, Zhu, et al., 2021; Ni et al., 2021) or a function of time in the case of a dynamic model (Nourinejad & Ramezani, 2020). The demand function is also often related to the passenger arrival function (Ke, Zhu, et al., 2021; Nourinejad & Ramezani, 2020). Figure 2 depicts the connection between the network and demand representation.

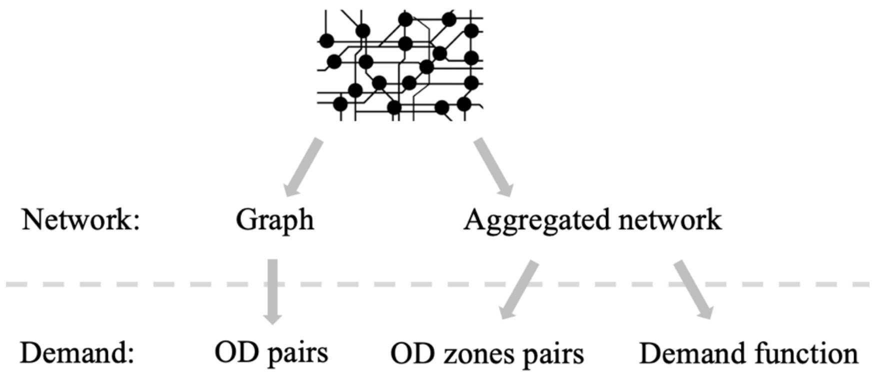

Figure 2. Network and demand representation

In general, the demand refers to the passengers that want to use the transportation network. This means that the notion of demand is closely related to the expression of waiting passengers and their waiting time. The number of waiting passengers often depends on their arrival and boarding rates (Nourinejad & Ramezani, 2020). However, in many modelling studies, the authors prefer to use the average waiting time of passengers instead of using the number of waiting passengers. It can be expressed in many ways: it can be given as a function of the number of vacant vehicles (Ke et al., 2020; Ke, Zhu, et al., 2021), a constant average time (Ke, Zhu, et al., 2021), a function of demand and matching rate (Nourinejad & Ramezani, 2020; Zhu et al., 2020), or as waiting cost (Ni et al., 2021).

2.3.3.2 Supply representation

In the transportation network, the supply is the number of vehicles that can serve passengers. The main transport modes covered in urban mobility studies are public transport, ride-sourcing, taxi, ride-sharing, and private vehicles. In addition, it is important to consider that travellers may also choose non-motorized travel modes such as walking or cycling.

For public transport, in the short-term perspective, the routes of vehicles are pre-defined, and the fleet is fixed, which is easy to model. Even though there might be competition between public transport companies, any public transport mode fosters the transition to the collective optimum. Thus, the transport modes that cause more concerns are those where private vehicles are used. The majority of studies that examine competition and cooperation are focused on ride-sourcing, taxi, and ride-sharing modes. Their supply can be presented as different variables in static models: flow, fleet size (Ke et al., 2020; Ke, Zhu, et al., 2021), or the number of drivers (Ni et al., 2021). In dynamic models, an accumulation variable is usually used (Nourinejad & Ramezani, 2020; Ramezani & Nourinejad, 2018).

To define the behaviour of vehicles, a fleet management component is often used. There are two main behaviour variations of ride-sourcing, taxi and ride-sharing companies: They are either idly moving to look for a new customer without being matched yet (Ni et al., 2021; Nourinejad & Ramezani, 2020; Ramezani & Nourinejad, 2018) or non-moving waiting for a new demand request (Ke et al., 2020; Ke, Zhu, et al., 2021). The first behaviour is prevailing among taxis. Another possible option is that a vehicle is dispatched to another region with higher demand (Ramezani & Nourinejad, 2018). After arrival to the new region, the vehicle acts according to one of two patterns described above. Besides, this is not applied to drivers who do not work for a transportation company and only occasionally take other passengers for ride-sharing. The behaviour of private vehicles depends on the personal needs of drivers.

On the other hand, it is trivial to define the behaviour of occupied vehicles as they would transport the customer from their origin to their destination. However, in the case of ride-sharing, the vehicle can make a detour to pick up another customer (Zhu et al., 2020). The transportation system's traffic state influences the time, speed, and travel distance of an occupied vehicle or of a vehicle that needs to pick up a customer. Knowing those parameters, it is possible to compute the congestion level, which may be used to estimate and reduce emissions rates.

Vehicles' representation in modelling ride-sourcing, taxi, and ride-sharing services is closely related to drivers' behaviour and their incentives. Most of the time, drivers seek a higher wage and fewer costs (Ni et al., 2021; Nourinejad & Ramezani, 2020). They are also sensitive to the market's benefit attractiveness and decide to enter or leave the market based on the demand level (Ni et al., 2021; Nourinejad & Ramezani, 2020).

2.3.3.3 Matching supply and demand

One of the most essential parts of modelling is to match the demand and supply. A common and straightforward way is to use the Cobb-Douglas type meeting function (Nourinejad & Ramezani, 2020; Ramezani & Nourinejad, 2018; Zhu et al., 2020). It is used originally in economics to model the relation between production output and production inputs (McKenzie, 2020). For a set of n inputs, the general form of the Cobb-Douglas function is

$$Y = f(x_1, x_2, \dots, x_n) = \gamma \prod_{i=1}^{n} x_i^{a_i}$$

where Y is output, x_i is input i, and γ, a_i are parameters that determine the general efficiency of production and the sensitivity of output to changes in the input quantities (McKenzie, 2020). In transportation, this function is used to calculate the matching rate based on the supply and demand quantities.

Another less explicit method to match supply and demand is to use Little's law (Ke et al., 2020; Ke, Zhu, et al., 2021). Little's law is a part of queuing theory and states that the average number of items in a stationary queue system is equal to the average time that an item spends in the system multiplied by the average item arriving rate (CFI, 2020). In transportation modelling, it is used to formulate the conservation equation of vehicles using the demand arrival rate and the average waiting time for a service. In Ni et al. (2021), the authors connected the supply and demand via a cost function similar to the Cobb-Douglas structure.

2.3.3.4 Expression of time and distance

To represent the behaviour of both passengers and vehicles, it is essential to introduce the notions of time and distance in the modelling process, In order to make the model more detailed and realistic.

Often, it is not clearly explained in studies what authors imply as a "waiting time" – if it is the time to match a passenger and a vehicle, the time for a vehicle to reach a passenger, or both of them together. Moreover, many economic-oriented studies do not consider waiting time at all or do it implicitly.

In static models, the notion of time is expressed as follows. In Ni et al. (2021), the authors did not aim to study traffic congestion but rather to model the market state. Thus, they did not use the notion of time for vehicles, but instead, they represented the waiting time of passengers in terms of cost. In Zhu et al. (2020), the trip time for both ride-sourcing vehicles and public transport are OD-based constants; the waiting time is calculated based on the Cobb-Douglas type meeting function considering the demand. For ride-sharing trips, detour time is approximated using an inverse proportion to the number of matched ride-sharing trips. Ke, Zhu, et al. (2021) assumed the constant waiting time for public transport while the average waiting time of ride-sourcing service is approximated and influenced by the number of available vehicles. For both travel distances of different transport modes and their speeds, average and constant values are utilised to estimate the trip time. In Ke et al. (2020), the average waiting time is assumed to be inversely proportional to the number of non-occupied vehicles while the average trip time is constant. The average travel time for ride-sharing is based on the probability of being matched and the average travel times of unsuccessfully and successfully paired users.

In dynamic models, the time is expressed as follows: In Nourinejad & Ramezani (2020), the expected waiting time of passengers and vehicle cruising time is approximated using Little's formula with waiting riders or vehicles and the matching function. In contrast, travel time is considered exogenous and constant. The notion of time is not used explicitly in Ramezani & Nourinejad (2018) but is approximated using the fleet size. In (Guo & Huang, 2022), the waiting time for passengers to be matched is a function of the demand rate and the fleet size and includes the Cobb-Douglas type meeting function, while the waiting time to be picked up and travel time is constant. In Pi et al. (2019) the waiting time of public transport modes is constant, walking time is calculated knowing the travel distance, and travel time for different modes is estimated using a mesoscopic dynamic network loading model. This work also includes the estimation of parking cruising time which is based on the expected parking occupancy. Waiting time for ride-sourcing is included in the travel time.

In the majority of studies, the distance is not expressed explicitly, but rather using the time notion. E.g., in Guo & Huang (2022), Ke, Zhu, et al. (2021), Pi et al. (2019) and Ramezani & Nourinejad, travel distance is expressed through travel time. In other studies, authors prefer to use constant values. For the sake of simplicity, Ramezani & Nourinejad (2018) and Ke, Zhu, et al. (2021) used the average constant trip length. The study of Ni et al. (2021) used the distance between the centres of demand regions to denote the travel distance.

2.3.4 Equilibriums

In this section, we discuss the possible equilibrium states of a transportation system that are covered in the literature. There are two market states according to the number of operators: a monopoly market and an oligopoly market. In the former one, there is a single company that monopolises the market. However, this is not relevant for our study as we study a multi-actor system. In the oligopoly market, there are several operating companies. A special case of an oligopoly market is a duopoly market with two companies. There are several studies that cover different aspects of duopoly systems. For example, Bryan & Gans (2019) state that the idle distance in a duopoly market when users are multi-home (users are not loyal to one service but choose the one with the best immediate offer) is lower than in a monopoly for ride-sourcing companies. Single-homing and multihoming drivers and passengers raise new research questions about the competition in a duopoly market (Zhou et al., 2021). It is also essential to study the behaviour of services if they are aggregated in one platform, e.g., MaaS. Zhou et al. (2021) discloses that such market measurements as platform profit, social welfare, and inefficiency degree were not yet fully covered in studies about duopoly and oligopoly. It is noteworthy that only a few studies assumed oligopoly, such as Ni et al. (2021) and Zhou et al. (2021). Below we describe the possible equilibrium states:

- **Operator-centric.** In this equilibrium state, each operator tries to maximise its profit. Thus, the objective function is a maximisation of the profit of transportation companies obtained from the fares paid by the customers minus operational costs and drivers' wages. One of the strategies to maximise profit is by determining a trip fare and fleet size (Ke et al., 2020; Ke, Zhu, et al., 2021). Ke, Zhu, et al. (2021) state that the fleet size can be controlled via the drivers' wages for ride-sourcing companies. If only one operator is present in the market, the market state is called a monopoly, and the equilibrium is a monopoly optimum.
- **Social optimum**. It is also known as the "First-best solution". It is often considered as a perfect system optimum. This strategy maximises the total social welfare, i.e., a sum of services' profit and consumer surplus (Ke, Zhu, et al., 2021). Consumer surplus is a measure of consumer welfare and is defined as the excess of social valuation of a product over the price paid by the consumer (Khemani & Shapiro, 1993). Thus, the objective function is a maximisation of the social welfare minus operating costs and drivers' wages. However, the profit of companies under the social optimum is always negative, which is proven in Ke et al. (2020) and Ke, Zhu, et al. (2021). Therefore, if the authorities want to implement it, they need to provide subsidies to the transportation companies (Ke et al., 2020; Ke, Zhu, et al., 2021).
- **Second-best solution.** According to Ke et al. (2020) and Ke, Zhu, et al. (2021) this strategy balances the optimal social welfare and companies' profit as it assures that the latter is higher than a certain threshold. Hence, the objective function is the same as in the social optimum case but subject to companies' profit being higher than a specific value. Thereby, it is a trade-off between the two aforementioned strategies.
- **Operator-centric with authority constraints.** Another equilibrium can be reached by applying authority constraints to selfishly acting operators. Depending on the problem formulation, those constraints can be strict (no possibility of violation), or loose meaning if an operator violates the constraints, it causes the service an extra cost to pay.

2.4 KPIs in competition and simulation

This section describes the KPIs that are often considered in research papers about the competition in urban transportation, as well as the parameters that influence KPI values.

In Zhang & Nie (2021a), the authors examined the competition between two platforms. Each platform provides ride-sourcing and ride-sharing (pooling) services. The authors examine how ride-sourcing and ride-sharing in both monopoly and duopoly markets influence passenger waiting time and market share KPIs. The study states that the duopoly lowers the price of ride-sharing and, therefore, the pressure of competition encourages the operators to promote ride-sharing. The authors also explore how pricing games between two platforms without regulations impacts social welfare, the equilibrium price, waiting time, and occupied and vacant vehicle time. According to their results, setting the minimum wage prevents the market from self-destructive price competition. It is noteworthy that those results are relevant for short-term planning. Matching and pooling efficiency are other factors that influence waiting time, platform profit, and wage rate in a duopoly market.

Zhou et al. (2020) study the impact of a platform-integrator on the competition in an oligopoly market. The authors compare the characteristics of a competitive market with the situation when a third-party service integrates all the operators. Implementation of an integrator increases total realised demand which in the usual case decreases with the increase of the number of operators. Also, the trip fare is decreasing with the increasing number of operators for both situations with and without an integrator. If a relatively low number of operators are integrated, their revenue increases as the demand increases, even when the fare decreases. However, with a large number of integrated operators, their profit decreases as the fare reduction becomes prevailing over the demand increase. Additionally, platform-integrator improves social welfare by reducing market fragmentation costs caused by competition.

The study of Liao (2021) states that the factors that influence the level of competition of ride-sourcing services with public transport are the following: 1) the travel time by ride-sourcing is less than 15 min or the travel time by public transport is significantly longer than the ride-sourcing alternative; 2) a trip with public transport requires several transfers; 3) weather condition; 4) high-density and high-diversity areas; 5) level of access to public transport. According to Liao (2021), ride-sourcing trips compete with public transport when they are performed during public transport operating hours, and the pick-up and drop-off points situated next to public transport stations.

In Pandey et al. (2019), the authors examine the competition of companies that provide both ride-sourcing and ride-sharing services. The optimization goal of the model is to minimise the cost of assigning a vehicle to a customer. Considering scenarios with the number of competing companies in the market varying from 2 to 5, the authors study the average cost difference from the optimal cost for each scenario. This difference is called an optimality gap. Several observations are deduced:

- The cost optimality gap increases with the number of companies. When the third company is added to the market, the optimality gap experiences the biggest jump: the optimality gap increases by an average of 2.17%. This means that more competition worsens the system performance.
- The optimality gap also increases when the number of customers increases. This means that having more customers increases the impact of competition and leads to a higher cost difference.

The study of Pandey et al. (2019) also states that an increase in the percentage of customers with a preference towards any company amplifies the cost optimality gap. To maintain the service rate (the ratio of serviced customers to the total number of customers), waiting time, and detour time at an acceptable level in a competitive market with customer preferences, the companies need to increase their fleet size, which will provoke more congestion.

In Ni et al. (2021), a competitive ride-sourcing market was modelled with network equilibrium, where a parameter sensitivity analysis was performed. The main obtained insights are the following: the market equilibrium price increases and equilibrium travel quantity decreases with the passengers' transaction cost, drivers' travel cost, operators' operating cost, and the number of demand regions; the market equilibrium price decreases and equilibrium travel quantity increases with the number of operators and/or drivers.

The study of Ke, Zhu, et al. (2021) explores the complementarity and competition of ride-sourcing services to public transport. Three scenarios are examined: direct ride-sourcing ride, walking or biking with public transport, and the first-/last-mile ride-sourcing service. Notably, ride-sourcing vehicles can cover the first-/last-mile delivery of passengers and therefore compete with cycling or walking if the distance is not long enough. The authors state that ride-sourcing fares play a key role in the competition between the direct ride-sourcing rides and the bundling mode of ride-sourcing with public transport. Another parameter that can influence this competition is the fleet size of the ride-sourcing company. Considering a fixed first-/last-mile distance, at the monopoly optimum, the fare of ride-sourcing is higher and the fleet size is smaller than at the social optimum. This is consistent with the fact that in the monopoly scenario the company looks for high revenue by reducing operational costs (fleet size) and increasing the profit (fare). However, in the second-best solution, a small profit reduction can significantly improve social welfare. Thus, this study states that according to the analysis of the second-best solution it is possible to find a Pareto-efficient strategy that satisfies both the social welfare and the profit of ride-sourcing service. The Pareto-efficient solution is an economic state where resources cannot be reallocated to make one actor better off without making the other worse off (Ke, Zhu, et al., 2021). The same study examines the dependencies of ride-sourcing fares, the number of vacant vehicles, and demand rates for each of the three scenarios.

Similar settings are examined in Zhu et al. (2020), but with an additional ride-sharing service. Some of the key findings are the following. Public transport is the primary mode for travellers who need only one transfer ride to reach a public transport hub. At the same time, ride-sourcing is the primary mode for those who have both origin and destination in isolated areas. In the case of low ride-sharing fares, passengers commit long-distance ride-sharing trips, which reduces the number of public transport trips compared to the non-ride-sharing market.

Pi et al. (2019) show that the average passenger cost increases with respect to the demand level. As the network becomes oversaturated with the increasing demand, the cost of driving and park-and-ride passengers increases as well. To remind, park-and-ride transport mode is when a user takes a personal car to reach a public transport station. At the same time, the cost of public transport passengers remains almost the same, as the cost of public transport is constant. The average traffic and park-and-ride cost increase when the bus fare increases, as the park-and-ride cost includes bus fare. When the parking fare increases, the average costs of driving and park-and-ride increase substantially, as well as the average traffic cost.

In Beojone & Geroliminis (2021), it is investigated how the competition between ride-sourcing companies as well as their competition with ride-sharing services can influence traffic congestion, particularly if idle vehicles are cruising. This study is focused on the vehicle kilometres travelled (VKT) indicator as it is connected with congestion level, fuel consumption, and safety issues. It is stated that encouraging ride-sharing is not sufficient to reduce VKT. This indicator grows proportionally to the fleet size and can be restricted by banning idle cruising. The study says that the quality of service highly depends on the passenger waiting time. It can be improved by dispatching vehicles to the areas with high demand and ameliorating matching efficiency and routing choice. After improving those characteristics, the only way to decrease the waiting time is to increase the fleet size. However, the increase in the fleet will eventually lead to a decrease in network speed and sequentially the increase in travel time. The authors also state that the willingness of passengers to share a ride would decrease the travel time and the fleet size in the optima.

In some studies, researchers examine the factors that influence the "price of anarchy" (PoA). The PoA is an indicator that shows how close a solution is to the social optimum, or, in other words, it measures the inefficiency of equilibrium (Zhou et al., 2021). Thus, it is an indicator of social equity. The PoA is often called an inefficiency ratio and can be defined differently. E.g., in (Amini et al., 2022), it is defined as the difference between the total travel time under the user equilibrium and social optimum. In Zhou et al. (2021), it is calculated as the ratio of the social welfare under a competitive market to the social welfare under a social optimum. Zhou et al. (2021) claim that the PoA depends on the number of competing companies. Notably, the authors state that as this number strives for infinity, the oligopoly market becomes a perfectly competitive market, which results in social optimum.

2.5 Schemes to foster collaboration over competition

This section covers the solutions that are studied to mitigate the externalities of competition and achieve cooperation. The majority of policies regulate the operations of ride-sourcing services as those services often compete with each other and with public transport, increasing the pressure on the transport system. The topic of regulating the competition between mobility providers remain under-researched, and there are only a few relevant studies that are presented in section 2.5.1. Most of the studies explore the possibility of reducing the impact of ride-sourcing activities in a monopoly market. Those policies are presented in section 2.5.2.

2.5.1 Competition regulations

The study of Yu et al. (2020) analyses the possible regulations that can be applied by the government in order to prevent the traditional taxi industry from being displaced by ride-sourcing services. This could be possible if the fares of taxis are at high levels, while the fares of ride-sourcing companies are low and their fleet size is high. However, as soon as the taxis are driven out of the market, fares of ride-sourcing services will increase. Thus, there is a need for policies to regulate the competition. Three situations are compared: 1) ride-sourcing services are freely operating without any restrictions; 2) certain regulations are applied to the market actors; 3) complete ban of ride-sourcing services. The proposed regulations are inspired by the already implemented policies in the US and China. For ride-sourcing services, the authors suggest putting a cap on the number of vehicles as well as imposing a market entry fee for drivers. In reality, those measures represent the limited number of licences granted by the government for ride-sourcing drivers to operate or special eligibility criteria imposed on the vehicles and drivers. The authors consider a two-period model. In the first period, the government applies the regulations and uses the eligibility constraints for drivers to enter the market. It is presented as a market entry fee and each driver decides whether to be hired by the service or not. In the second period, the ride-sourcing service adjusts its fares and wages considering the price and wage sensitivity of users and drivers. At the same time, drivers decide whether to start operating or not. The policies provoke a decrease in ride-sourcing drivers, which sequentially forces the service provider to increase the wages for the rest of the drivers. Finally, compared with the complete ban of ride-sourcing services, those policies balance different objectives: the taxi industry survives, while ride-sourcing service profit, drivers' wages, and consumer welfare increases.

Another solution proposed by Yu et al. (2020) to reduce congestion, regulate the competition, and balance the welfare of stakeholders is to allow the government to define the taxi fares. This will make the taxi service more competitive and reduce the number of ride-sourcing vehicles. Thus, the objectives of this study are 1) to assess the authority regulations that are implemented in the reality; 2) to capture the interaction between the government and ride-sourcing services, particularly, the reaction of the latter to the restrictions; and 3) to see how the decision adjustments of ride-sourcing services influence taxi service.

Zhang & Nie (2021b) examine the effect of the minimum wage applied to a company that provides both ride-sourcing and ride-sharing services in a competing market with public transport. The usage of this regulation was inspired by a similar policy implemented in New York. Three scenarios are considered and their results are compared: 1) profit maximisation of the ride-sourcing company without any constraints; 2) profit maximisation under regulation policies; and 3) second-best solution (social welfare maximisation) with revenue-neutrality. The objectives of this paper are to investigate what influences passengers' mode choice and ride-sourcing company pricing strategies, model those decision processes, and study the effects of regulations. The main focus is on the company's profitability, market share, and social welfare. The results show that the minimum wage policy can improve social welfare in the short term, however, in the long term, the company takes back its advantage by recovering a part of the lost profits while reducing driver surplus (income minus expenses) and passenger surplus (passenger cost savings). In addition, in a market with both high demand and supply, the minimum wage policy can force passengers to completely abandon ride-sharing rides in favour of ride-sourcing services as the company will adjust its pricing strategy. The authors claim that this regulation can harm public transport usage by maintaining the artificially high ride-sourcing demand and supply levels.

Additionally, Zhang & Nie (2021b) examine the per-trip congestion charging policy for solo ride-sourcing trips without considering private vehicles in the model. The authors justified the choice of the policy by stating that it is under consideration in some US cities. The result of the analysis of congestion tax is also rather pessimistic. It shows the policy's negative impact on social welfare even if it encourages ride-sharing. However, the combination of both minimum wage and congestion charge policy brings balance to the system in the short term.

In Mo et al. (2020), it is examined which governmental strategies can foster ride-sourcing companies to use electric vehicles (EV). The authors consider a duopoly market with two heterogeneous companies, one of which owns the fleet (asset-heavy platform) and the other hires drivers with their own cars (asset-light platform). It was inspired by one Chinese ride-sourcing company that purchases its own vehicles and, to be subsidised by the government, chooses to possess electric vehicles. However, recently the Chinese government started to subsidise charging infrastructure too to support EV usage. Thus, two types of subsidies are examined: EV purchase subsidies and charging stations. This work aims to examine how the government resource allocation of subsidies can influence duopoly competition. Three types of drivers are considered: no-car owners, gasoline car owners, and EV car owners. They decide whether to operate on behalf of one of the ride-sourcing platforms or not to enter the market at all. At the same time, the users also have three choices: asset-heavy platform, asset-light platform, or public transport. To represent the relation between the charging station subsidy and the charging-related cost of drivers, the authors implemented the monetary charge cost, waiting time cost while charging, and searching for station cost in the model. It is discovered that when the passengers' waiting time cost function exhibits moderate increasing returns to scale, with the increase in both subsidies, the riding fare decreases and the consumer surplus increases. The increasing EV purchase subsidy leads to the profit and market share increase of the asset-heavy company but has an opposite effect on the asset-light platform. On the contrary, the growth in the charging station subsidy increases the market share and profit of both companies. The authors propose that authorities should coordinate and balance both types of subsidies with each other if there is enough budget; otherwise, to focus on the charging stations' subsidy.

In Zhu, Xu, et al. (2021), the authors considered the competition between public transport and ride-sourcing vehicles. Their model depicts the cooperative and competitive relations between the government and the ride-sourcing service, where the government maximises social welfare and the company is focused on profit. In this bi-level model, at the upper level, the government provides subsidies to passengers to use ride-sourcing for their first- and last-mile rides, therefore implementing policies to boost cooperation. At the same time, at the lower level, both the government and the company optimise their operation to pursue their own objectives, thus competing with each other. The outcome of the game is based on the users' choice of transport modes. It has been shown that subsidies can help regulate the fare and make ride-sourcing services a complementarity mode to public transport to solve the problem of first-/last-mile delivery of passengers from isolated households. The same policy was explored in Reck & Axhausen (2020). The ridership is low in the cities where this policy is applied. The authors considered the following theories: 1) the disutility of the additional transfer between the ride-sourcing and public transport together with pick-up waiting time reduce the travel time savings; 2) user expenses still exceed the value of travel time savings, especially for low-income households. This study quantifies the influence of each reasoning both conceptually and empirically using a simulation of service trips in three US regions. Thus, the paper compares the impact of each theory on travel time savings considering “ride-sourcing + public transport”, “walking + public transport”, and “car-only” options. An initial outcome is that the subsidy schemes are inequitable as they benefit high-income households. Besides, the additional transfer disutility and wait times exceed travel time savings for short distances, while it is still practical to use a private car for long distances. On the contrary, the study of Brown et al. (2021) analyses the data from a pilot program launched in Los Angeles and concludes that it had relative success. However, the authors agree that this travel option can be inaccessible for vulnerable population groups as it requires having a smartphone and a bank account.

As it is obvious, in most studies, the competition of a ride-sourcing service with other modes of transport is examined: taxis (Yu et al., 2020) and public transport (Reck & Axhausen, 2020; Zhang & Nie, 2021b; Zhu, Xu, et al., 2021). Only the study of Mo et al. (2020) covers the effect of government policies on a duopoly ride-sourcing market. This study explores the influence of the EV policy on the position of companies in the market, notably, their market share and fares. However, it does not mention the changes in the externalities of competition. Thus, as mentioned before, this study examines which strategies can foster ride-sourcing companies to use electric vehicles but not the policies to reduce the impact of competition. Eventually, we can state that the regulations that are meant to mitigate the externalities of mobility services’ competition (especially within the ride-sourcing market) are not studied enough at the current stage.

2.5.2 General regulations

Governmental regulations that intend to lower the impact of ride-sourcing activities on the network traffic state can be classified as follows:

1. Pricing regulations:
    a. Congestion charges
    b. Other charges
2. Restrictive regulations:
    a. Wage constraint
    b. Utilisation rate constraint
    c. Cap on the number of drivers
    d. Commission cap
3. Other regulations:
    a. Fare regulation
    b. Parking strategy
4. Subsidies

2.5.2.1 Pricing regulations

Congestion charge

A prevalent pricing regulation to reduce the impact of ride-sourcing vehicles is a congestion charge. In (Li, Yang, et al., 2021), several strategies for implementing the congestion charge are described: a) a one-directional cordon charge on ride-sourcing vehicles that enter the congestion area; b) a bi-directional cordon charge on ride-sourcing vehicles that enter or exit the congestion area; c) a trip-based congestion charge on all ride-sourcing trips (idle vehicles cruising for passengers are exempted). The first and the second charges are imposed on all ride-sourcing vehicles that cross the cordon both with a passenger or idle. The authors assume that if a vehicle has a passenger on board, the cordon-based charge is paid by the passenger, while for an idle vehicle it is paid by the driver. The third type of toll, trip-based, is paid only by the customer. When a charge is imposed on a customer, it becomes a part of the user's travel cost and, thus, changes the demand function. If it is imposed on a driver, it influences the driver repositioning model and supply function. However, the authors decide to include the driver's charge in the objective function as both formulations of the driver's charge are mathematically equivalent. According to the results, the imposed extra cost on service operations is mainly covered by the company rather than by passengers and drivers for all charge strategies. The first strategy reduces the traffic level in the concerned zones and the fares outside the congestion areas. Compared with other strategies (bi-directional cordon charge and trip-based congestion charge), the first strategy imposes fewer costs on the service provider, passengers, and drivers to reach the same level of congestion reduction. However, the third strategy is more effective in terms of tax revenue: in order to ensure equal revenue for the government, it imposes fewer costs on the service provider, passengers, and drivers.

Congestion charges are also examined in Li, Poolla, et al. (2021). Their strategies are the following: a) a charge per trip; b) a charge per vehicle operating hour (whether or not it has a passenger). The first strategy is covered as well in Beer et al. (2017). Li, Poolla, et al. (2021) calibrate their model using the ride-sourcing data from San Francisco. They suggest two ways of implementing per-trip charge in the model: include it in the user travel cost in the demand function or add it to the expenses of service in the objective function. The second option was used due to its simplicity. In the case of the time-based charge, it is imposed on all ride-sourcing vehicles based on the number of operating hours. In the model, similarly to the per-trip charge, the time-based charge can be also levied either on drivers or on the service. Li, Poolla, et al. (2021) state that the decrease in the number of ride-sourcing vehicles due to both charge strategies is not significant and limited by the wage floor of drivers. The study favours the time-based charge as it penalises both idle and occupied vehicles and hence increases the occupancy of vehicles. According to the result, the time-based charge leads to higher passenger surplus, platform profits, and tax revenue, while the drivers are not affected, and thus is Pareto superior to the trip-based strategy.

The per-trip congestion charge was also mentioned in Li et al. (2019). This charge is added to the passenger travel cost function. The study says this charge increases fares and decreases service profits and drivers' earnings. Contrary to Li, Poolla, et al. (2021), the results show a decrease in ride-sourcing vehicles (by 11.9%) and the number of trips (17.1%).

The per-trip congestion tolling was examined in Vignon et al. (2021), inspired by the experience of New York City. This charge is implemented in the objective function (revenue maximisation) and subtracted from the revenue of the company. However, the authors favour a commission cap approach instead (when an authority puts a cap on the service commission from each realised ride), stating that it is more efficient in improving social welfare. They also mention that in the case of the monopoly market, the value of the tolling charge should first increase with congestion but then decrease, as the company naturally aligns with the regulator's objectives when the congestion is very high.

A flat cordon-based congestion charge applied to a company that provides both ride-sourcing and ride-sharing services is discussed in Zhang & Nie (2022). According to it, ride-sourcing vehicles are charged when they enter the city centre with zero or one passenger, thus promoting ride-sharing. In the case of an empty car relocating, this charge is a part of the drivers' operating cost. Otherwise, if a vehicle carries a passenger, the fee is integrated into the trip fare. On the passenger side, they can choose public transport, ride-sourcing, or ride-sharing. The results show that this policy results in gains in the social welfare, however, its positive social and congestion impact is moderate in comparison with the trip-based congestion charge.

Other charges

In Zhang & Nie (2022), it is proposed to charge a flat congestion fee on all solo ride-sourcing trips with pick-up and/or drop-off points in the city centre (ride-sharing trips are exempted). In the model, this charge is integrated into the trip fare. This policy showed promising results: it reduces traffic congestion, maintains the same level of service, increases social welfare, and significantly contributes to the local budget.

Another similar fee that can be possibly introduced but not yet explored by studies is a charge for having both pick-up and drop-off points next to public transport.

2.5.2.2 Other regulations

Wage constraint

In Li et al. (2019), this regulation is implemented by putting a constraint on the function of driver's earnings. The results show that putting the lower bound on drivers' wages increases their employment, improves pick-up time, decreases fares, sequentially attracts more passengers and increases the number of trips. However, it reduces the profit of a ride-sourcing service provider. The simulation in Li et al. (2019) has the following results: increasing driver wage by 23.3% will increase the number of vehicles by 23.3%, increase ridership by 24.6%, improve the pick-up time by 10%, decrease the travel cost by 3.6%, and reduce the platform profit by 10.5%. It is noteworthy that the influence of the wage floor on traffic congestion is not shown.

Zhang & Nie (2021b) also examine the effect of the minimum wage. The results show that this policy can improve social welfare (excluding environmental impact) in the short term, however, in the long term, the company takes back its advantage by reducing driver and passenger surplus. In addition, in a market with both high demand and supply, the minimum wage policy can force passengers to completely abandon ride-sharing rides in favour of ride-sourcing services as the company will adjust its pricing strategy. The authors claim that this regulation can harm public transport usage by maintaining the artificially high level of ride-sourcing demand and supply.

In Ke, Li, et al. (2021), considering homogeneous drivers, the results show that this policy is not Pareto-efficient if the targeted Pareto-efficient solution situates between the monopoly optimum and social optimum. The cause is that if the wage at social optimum is lower than the wage at monopoly optimum, the latter wage is chosen automatically. When the wage at the social optimum is higher than the wage at the monopoly optimum, the targeted solution is not Pareto-efficient. It also attracts new drivers, which creates more congestion.

Utilisation rate constraint

Ke, Li, et al. (2021) mention that recently, a new policy was implemented in New York City called the minimum utilisation rate regulation. According to it, the ride-sourcing drivers need to carry a passenger at least 69% of the operating time in a certain zone. However, the authors state that this regulation is not Pareto-efficient since the platform would decide to serve fewer passengers and employ fewer drivers under mild congestion.

Utilisation rate constraint sometimes is also called cruising cap policy. It is studied in Zhang & Nie (2022), where firstly the vehicle utilisation rate in the city centre is calculated and then used to estimate the lower bound. In this way, the threshold is set. The authors are sceptical about it, because, according to their results, it relieves the congestion but increases the number of private cars that benefit from the reduced traffic. It also leads to a negative impact on social welfare.

Cap on the number of drivers (vehicles)

Another possible regulation is to limit the number of instantaneously operating drivers (vehicles). In Li et al. (2019), the results show that the limitation of the number of vehicles has a negative impact on drivers as the service provider hires lower-paid drivers. It also provokes longer pick-up time and a sequential decrease in demand.

As mentioned before, Yu et al. (2020) also studies this regulation in a bundle with the market entry fee for drivers to show how it can influence taxi industry survival and the formation of fair prices. This will provoke a decrease in ride-sourcing drivers, which sequentially forces the service provider to increase the wages for the rest of the drivers. Finally, it balances different objectives: the taxi industry survives, ride-sourcing service profit, drivers' wages, and consumer welfare increase.

According to Ke, Li, et al. (2021), a similar policy has already been implemented in Beijing, where the government allowed only the local residents to provide ride-sourcing services, which is a fleet size control. The authors argue that putting an upper limit on the fleet size can influence congestion but not the social objectives, as the fleet size under the social optimum is much higher than under the monopoly optimum.

Commission cap

Considering a monopoly market, in Vignon et al. (2021), it was suggested to impose a cap on the commission ride-sourcing operators take on each ride. Firstly, considering a usual first-best commission for solo ride-sourcing rides, the authors stated that the commission for ride-sharing rides is inferior. Thus, there is already an existing natural non-binding cap on ride-sharing trip commission. Therefore, the market can be regulated by imposing only one commission cap. In the model, the commission cap is implemented as a constraint that the user fare minus driver reward is less or equal to the cap value. According to the results, putting a low commission cap is more efficient in reducing the welfare gap than the congestion tolling approach. However, they can also be combined if a congestion charge is relatively small and, in this case, it is possible to reach any desirable sustainable equilibrium. Ke, Li, et al. (2021) claim that commission regulation leads to a Pareto-efficient solution.

2.5.2.3 Other regulations

Fare regulation

To reduce congestion, regulate the competition, and balance the welfare of stakeholders, Yu et al. (2020) propose to allow the government to define taxi fares. This will make taxi service more competitive and reduce the number of ride-sourcing vehicles.

Parking strategy

Beojone & Geroliminis (2021) state that implementing a parking strategy for ride-sourcing vehicles (vehicle waits at a parking spot in a high-demand area for the new demand request instead of idly cruising) would lower the waiting and travel time as the network is less saturated with idle cruising vehicles. The parking strategy helps the system recover faster after peak hours and hence improves system resilience.

However, several aspects require further study, such as an effective assignment of parking spots for vehicles. Another issue is that parking lots in high-demand areas are often payable, which raises the question if the government is ready to provide subsidies or free parking spots for ride-sourcing vehicles.

2.5.2.4 Subsidies

As previously mentioned, Mo et al. (2020) study two types of subsidies to stimulate electric vehicles' utilisation: subsidies for EV purchase and for charging stations. The authors propose that authorities coordinate and balance both types of subsidies if there is enough budget instead of focusing only on one of them. Otherwise, it is more relevant to be focused on the charging stations' subsidy.

In Zhu, Xu, et al. (2021), it is shown how subsidies can help regulate the fare and make ride-sourcing services be a complementarity mode to public transport to solve the problem of first-/last-mile delivery of passengers from isolated households. The same policy was explored in Reck & Axhausen (2020), where the authors doubt its effectiveness and equity for all population groups. The study of Brown et al. (2021) suggests that such a program launched in Los Angeles had relative success. However, the authors agree that this travel option can be inaccessible for vulnerable population groups.

3 Factors Affecting Fair Cooperation

3.1 General

The literature review carried out in the previous chapter revealed that the already limited literature is usually restricted to individual mobility actors and the impact of regulations on them, without considering the dimension of stakeholders, the interactions between them and the conflicting interests they usually have. Only a few studies cover the issue of competition regulations between the various mobility actors that shape the relations between them and determine the status of urban mobility. Fleet size cap, minimum driver wage, and congestion charge are some of the most popular regulations, however, the list of solution policies is limited, and we find that their influence on the competition externalities is not covered enough in the literature. Thus, it is necessary not only to deeply study the existing competition regulations but also to develop new approaches.

For this reason, it was deemed necessary to complement the literature review with a questionnaire survey addressed to mobility operators active in the DIT4TraM pilot cities, but also in other cities and regions of the EU. Representatives from public and private operators, service providers, SMEs and authorities from EU countries, indicated their organizational priorities and their attitude towards multiple aspects of competition and cooperation. The objective was to identify the most critical situations when the stakeholders perceive conflicting interests with each other, better understand their expectations, and the current technological and organizational processes used to improve cooperation. A more detailed presentation of the survey and its results can be found in the following sections.

3.2 Survey design and execution

In the first section of the survey, we asked all stakeholders to evaluate the importance of efficiency, safety, accessibility and environmental sustainability of the transportation system, as well as their organisations' financial viability and user satisfaction. The stakeholders were then asked to prioritise the above-mentioned factors according to how likely they were to motivate their organisations to participate in cooperation schemes. The survey was later differentiated based on whether the respondents represent public organisations, private companies or authorities. Taking into account the differences in Public-Private Partnerships and partnerships between private sector companies, questions addressed to public organisations and private sector mobility companies were revolved around the following dimensions:

- How has competition influenced organisations and what was the impact on the overall system?
- Are organisations willing to cooperate with others to improve system performance?
- What could be the possible fields of cooperation?
- Under which conditions would the different organisations be willing to participate in collaborations?
- Are there regulatory drawbacks or unfair practices in today's market?
- Are regulations needed to foster collaboration between transport operators?
- What are the concerns regarding data exchange?
- What would be the impact of permit, pricing, prioritisation or resources sharing schemes in the different organisations?
- What benefits would motivate the different organisations to participate in the mentioned schemes?
- Would decentralised, distributed or centralised approaches appeal more to the different organisations?

The questions addressed to the representatives of authorities on the other hand, were mainly focused on their willingness to get involved in different parts of the cooperation between mobility stakeholders. More specifically we assessed their interest in:

- Facilitating the cooperation between public and/or private mobility providers
- Becoming a data intermediary between the different providers
- Developing and operating an integrated information and ticketing platform
- Investing in infrastructure needed to support cooperation between mobility providers
- Promoting private services between residences and public transport stations
- Regulating private vehicles and mobility companies by imposing different schemes
- Providing subsidies to mobility companies
- Exploring new policies

The complete questionnaire can be found in Appendix A.

3.2.1 Description of Participants

As mentioned earlier, the distinct stakeholder groups that were selected for the purposes of this research were public operators, private operators, service providers, SMEs and public authorities. The reached stakeholders operated either in DIT4TraM pilot cities or EU cities/regions in general. As operators, we consider any public or private entity that is responsible for the maintenance and management of a transport service. We make a distinction based on whether these operators are publicly or privately owned because of the different gaols and objectives of the private and public sector. “Industry-service providers” includes providers of enhanced mobility through services and information as well as ITS solutions providers and data handling or software providers. “SMEs” represent the various small and medium-sized enterprises that operate in the field of mobility. “Public authorities” include cities and regions, transport authorities, road authorities and member states as well as National, European or International regulatory bodies. The synthesis of participants in the survey can be seen in Figure 3 . The total number of stakeholders reached was 17.

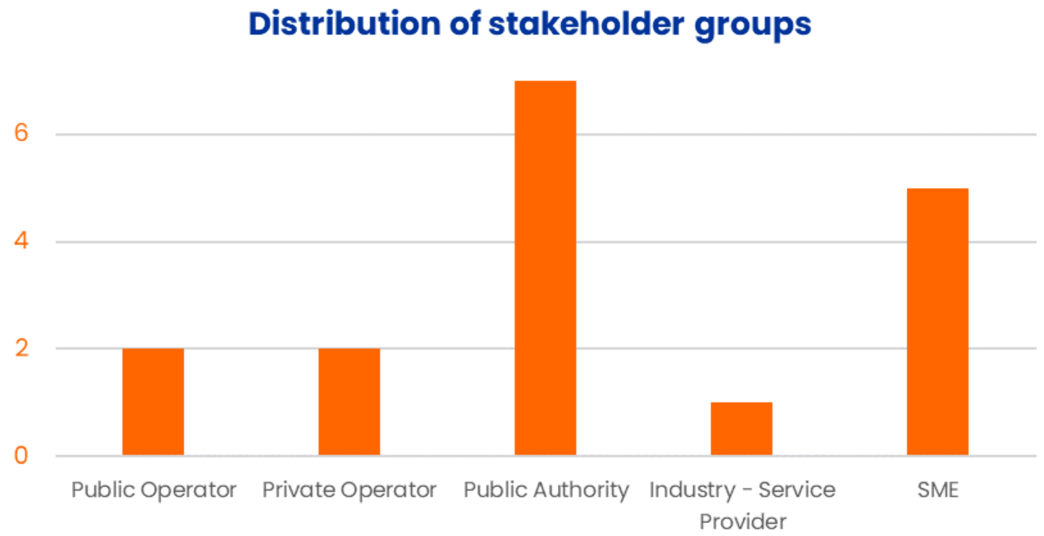

Figure 3. Number of participants per stakeholder group

3.3 Survey Results

In the first section of the survey, stakeholders were asked to state the importance (from 0 to 5) of a number of different objectives for their organization/company. More specifically, they rated the importance of transportation's system efficiency, traffic safety, accessibility and social equity, environmental sustainability, profit, overall financial viability and passenger satisfaction/loyalty. This resulted in the prioritisation of these objectives by stakeholder category as shown in Figure 4.

Figure 4. Organizational priorities per stakeholder group

It is easy to observe from the above figure that there are significant differences between the stakeholder groups on how they evaluate the importance of the different objectives. Indicatively, we see how important having profit is for private organizations (Operators, Industry and SMEs), as expected, while, at the same time, for public organizations (Operators, Authorities) it is clearly lower. A similar behaviour is also evident for the overall financial viability of the organization, however, the divergence there is smaller. On the other hand, it is clear that public organizations are more committed to issues related to social equity and environmental sustainability. As far as transportation's system efficiency and traffic safety are concerned, they seem to be equally important for all stakeholder categories, with the exception perhaps of companies representing the general industry and service providers, whose business is not related to the entire system's performance.

Next, stakeholders were asked to sort the key factors that would motivate them to participate in a cooperation scheme. The aggregated results are presented in **Fout! Verwijzingsbron niet gevonden.**. Again, it is confirmed that the main factors that drive public organizations are socially- and environmentally-oriented while private organizations are driven by financial motives. The distinction is made very clear, as maximizing profit is the most important factor for the private sector, followed by reducing operational costs and improving financial viability, which are the less important factors for public operators and authorities. It is worth noting however that SMEs seem to be an exception to the above rule probably because they emphasize more on their vision and mission as companies.

Figure 5. Prioritization of motives to participate in a cooperation scheme per stakeholder group

3.3.1 Competition between private and/or public organizations

After the first stage of the survey that was addressed to all stakeholders, the survey was differentiated into 3 alternative sections that targeted specific stakeholder groups; public operators, private operators and authorities. This was deemed necessary due to the different nature of the situations these organizations are called upon to address and the different roles they would play in a potential cooperation scheme. This subsection presents the results of the survey regarding public and private operators while 3.3.2 presents the results for authorities.

Figure 6 concerns the possibilities of cooperation between public and private organizations with the goal of improving overall system performance. We can observe that all participating public organizations are willing to participate in cooperation schemes around integrated transport services and data exchange. Private organizations are also generally willing to participate in cooperation schemes, especially with public transport operators but also with private operators, micro-mobility service providers, logistic companies and integration providers. However, some are reluctant to do so since they believe that companies have conflicting interests and such schemes cannot be beneficial for all parties involved.

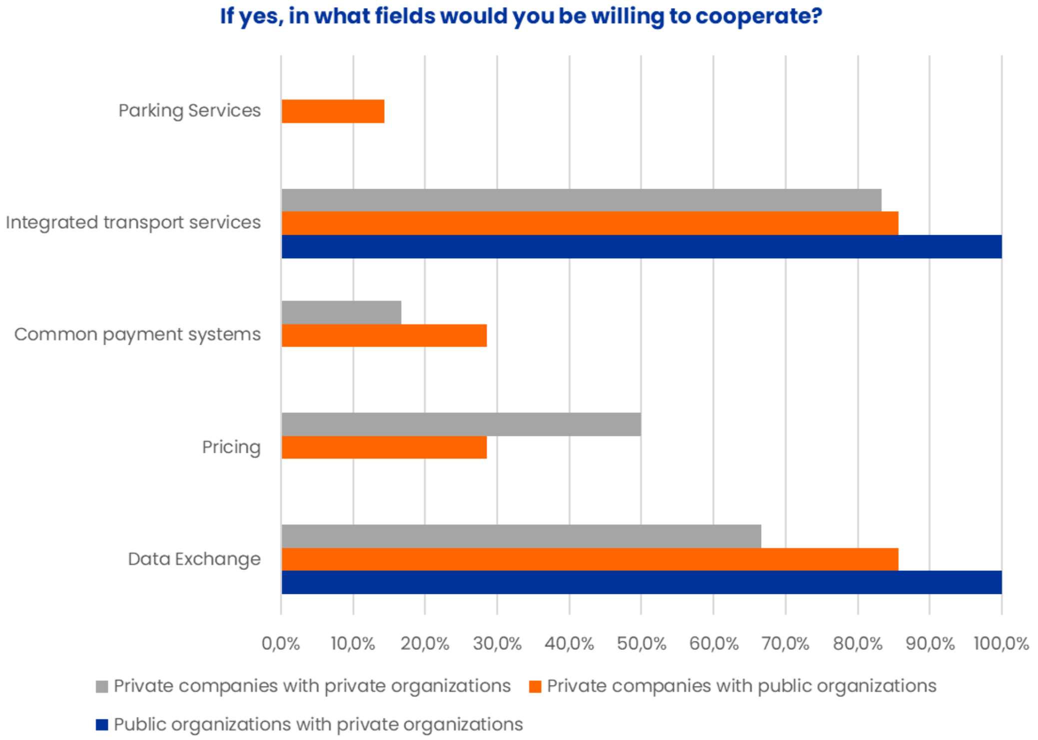

Figure 6. Exploration of cooperation possibilities between public and private organizations

When prompted to sort some selected cooperation conditions from the most important to the least important, in the basis of a Public-Private partnership, Public operators selected transparent data sharing as the most significant one while private operators didn't appear to consider it an important condition. Fair access to decision making, fair profit/cost allocation and fair market share allocation were viewed in a similar way by both groups.

Figure 7. Importance of different cooperation conditions for public and private organizations within a PPP

The private sector stakeholders were then asked to sort the same conditions but in terms of cooperation among private companies only. Compared to the case of public-private cooperation, some changes were observed. First, the importance of fair profit allocation was upgraded and was now considered more important than fair access to the decision making. This could imply a concern of private companies of being “oppressed” by public organizations’ procedures of decision-making within PPPs. Fair market-share was also upgraded as a necessary condition for cooperation between private companies, something that had less importance in PPPs.

Sort the following cooperation conditions from the most important (1st) to the least important (5th) in the basis of a cooperation between private companies.

Figure 8. Importance of different cooperation conditions of cooperation between private companies

Consequently, common regulatory drawbacks that hold private companies back from cooperating with the public sector, as also stated in the survey, include:

- Bureaucracy
- Cumbersome collaboration processes and agreements driven by complex performance monitoring regulations
- Long decision process in public sector
- Tender processes that may take "forever"
- Low level of transparency
- Price sensitive award mentality
- Lack of public funding
- Instability of the public sector during election periods

Regulatory drawbacks that hold private companies from cooperating with each other were not identified through the survey. Drawbacks to this kind of cooperation other than conflicting interests, usually stem from vision and company culture differences. Practices that are considered unfair in today's market were also not identified through the survey.

Regarding the level of digitalization within public and private organizations, a large divergence is observed. Private companies in general assess their digitalization level to 3.25 out of 5, with private operators assessing this level to 4 out of 5. Public operators on the other hand appear to have a lower level of digitalization; 2.5 out of 5. When it comes to using historical demand data, weather forecasting or special events data in order to make decisions, both public and private organizations assess their reliance in similar levels.

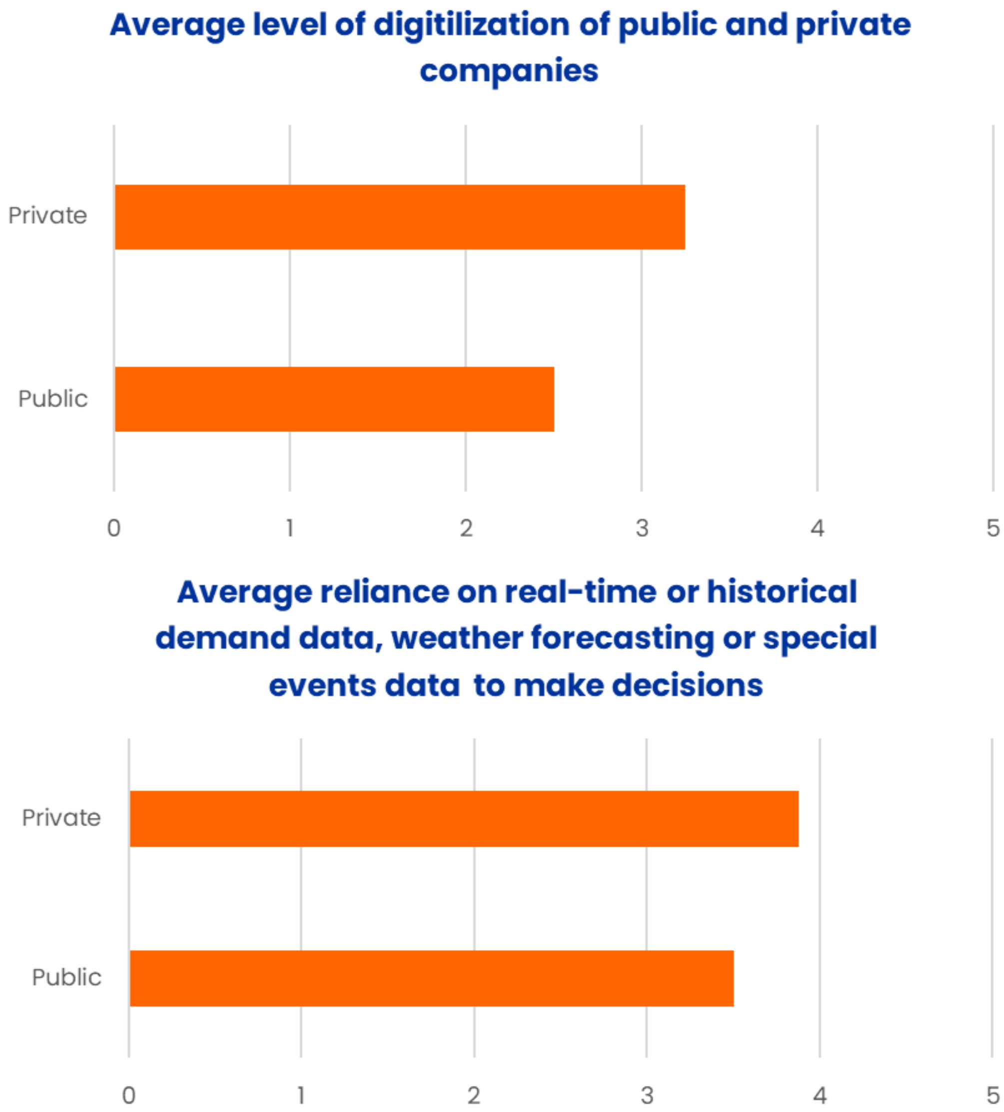

Figure 9. Level of digitalization and reliance on real-time or historical data of public and private organizations

The unrestricted availability of data, seems to be a bigger issue for private companies since all participating public organizations appear eager to provide their data to everyone. Private companies, on the other hand, treat their data as a valuable asset that could not be shared with competitors, among others. They would participate in data exchange schemes mainly if this could help increase their revenues/profit and secondarily if these schemes could benefit the society or academia, or they would not participate at all.

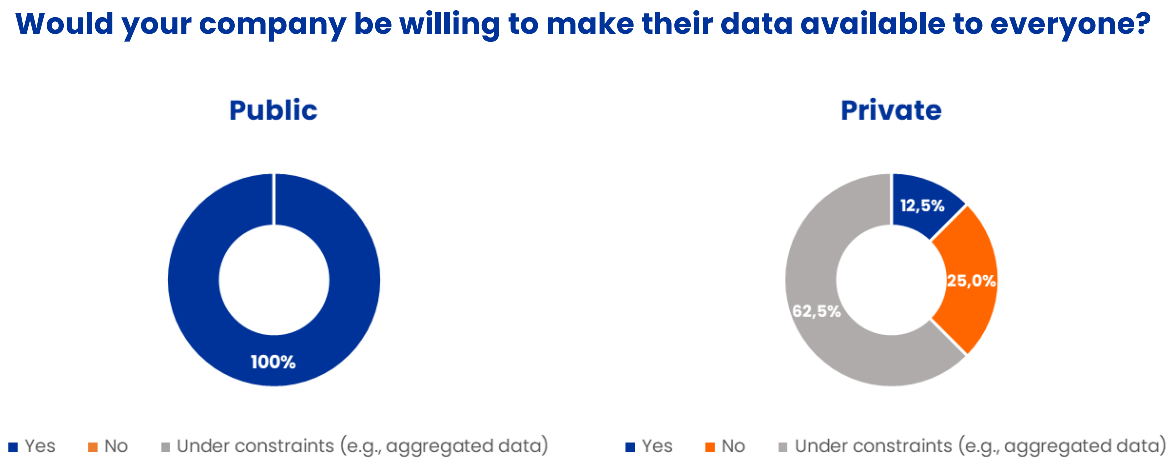

Figure 11. Willingness to provide organization's data to everyone

In the question "Are there any specific data that your company would like to have access to?" public operators stated that would like to have more detailed information regarding real-time occupancy rates on their routes while private operators, SMEs and service providers would generally like to have access to quantitative and qualitative data of traffic patterns and multimodality data with a focus on public transport data. Figure 11 presents a more detailed view of the cooperation possibilities among the private and public organizations, concerning data exchange and sharing.

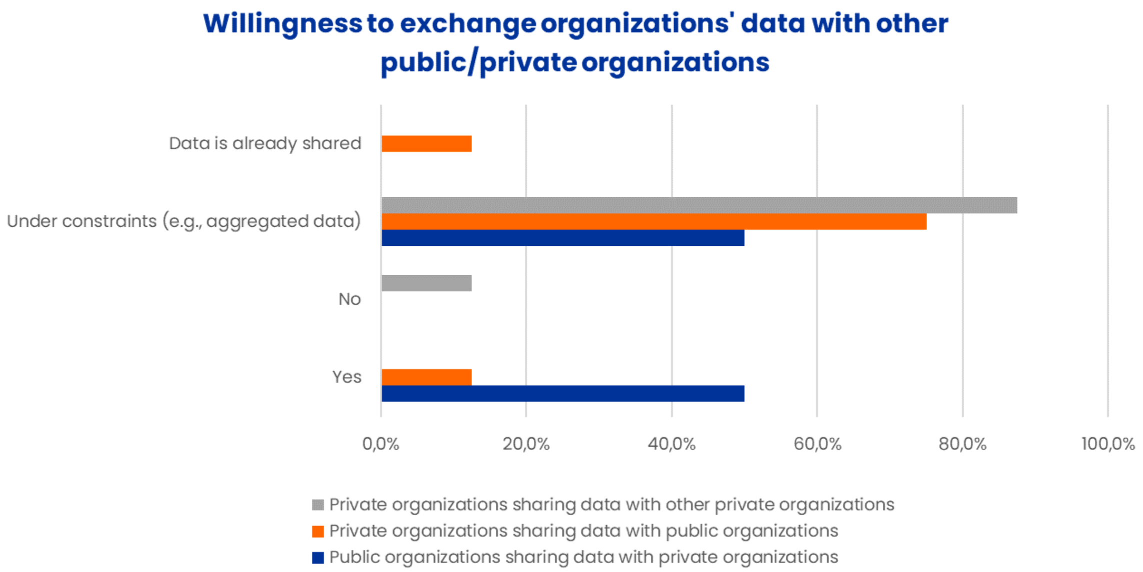

Figure 10. Willingness to participate in data-sharing cooperation schemes

While most mobility actors -both public and private- do not feel that their organization currently suffers from competition with other transportation companies that harm their business or the overall network efficiency, the

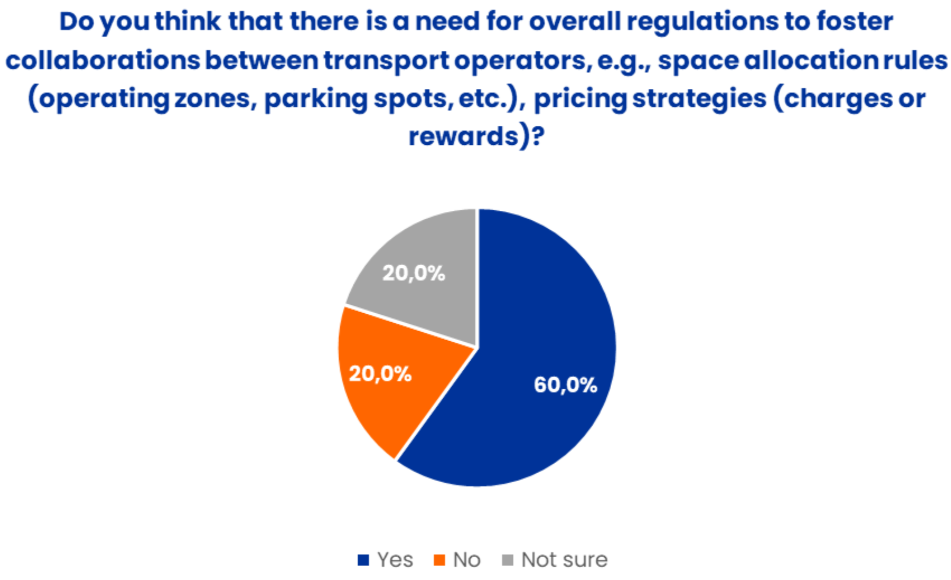

Figure 12. Need for overall regulations to foster collaborations

majority believes that there is a need for overall regulations to foster collaborations between transport operators (Figure 12).

Furthermore, it is not very clear for all the stakeholders, if the participation in such schemes would have a positive or negative impact on their organization, as it is shown in Figure 13. However, it is clear that through resource sharing, novel services can be provided that can generate added value and make the transportation system more efficient, so it can be beneficial for both public and private organizations.

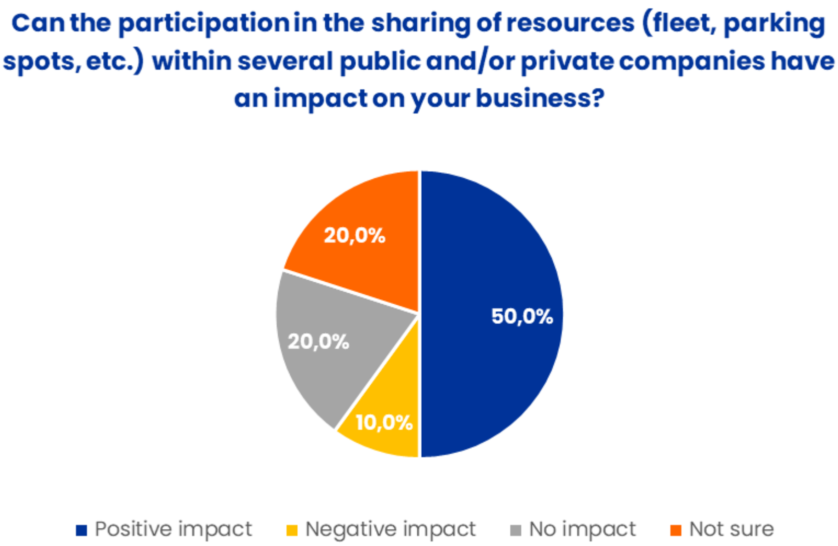

Figure 13. Impact of participation in sharing of resources

Pricing regulations are not very popular with both public and private stakeholders. On the contrary, the introduction of operating and regulating policies from local authorities (specific parking zones, operating hours, tradable credit schemes, etc.), appear more attractive to some private operators and SMEs as long as they create a "same rules-for-all" environment that benefits businesses with similar philosophy who strive for maximizing their customer experience.

Finally, the preferences of cooperation schemes among stakeholders are presented in Figure 14. Distributed systems seem to be the most attractive for private organisations, while public organisations seem to prefer centralised systems to the same extent. The decentralized schemes, that stand somewhere in the middle between centralized and distributed schemes, are the least appealing.

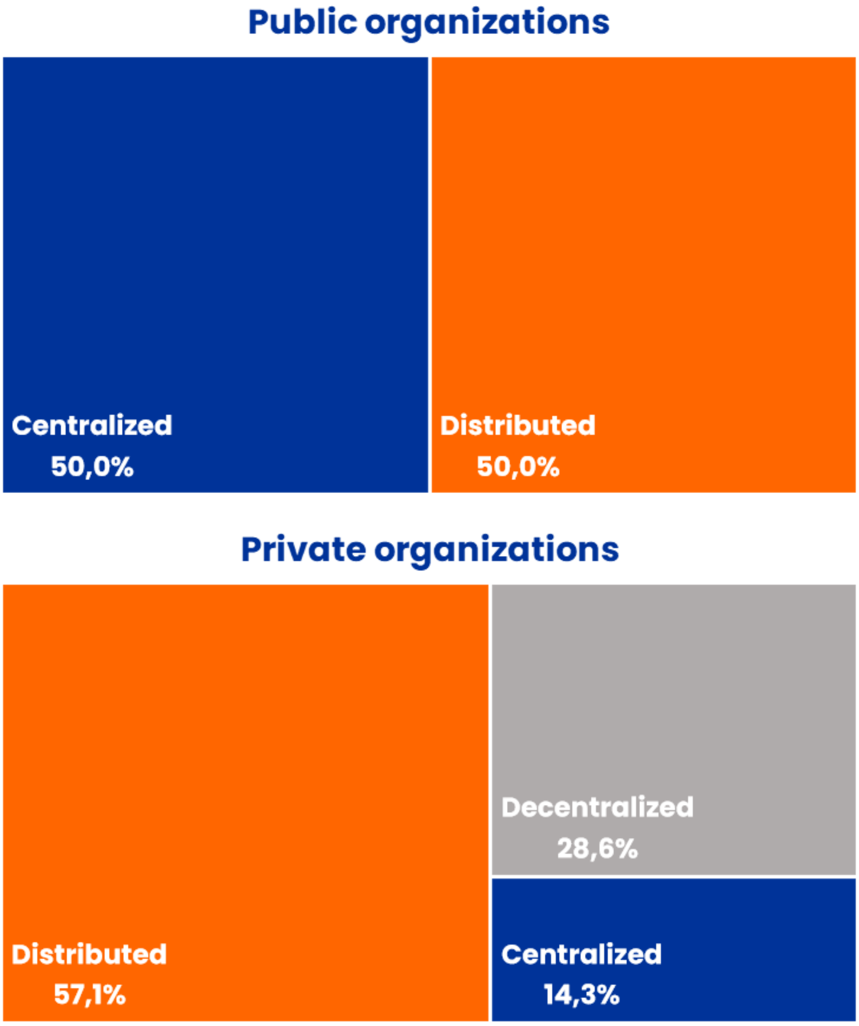

Figure 14. Treemaps of cooperation scheme preferences

3.3.2 Authorities

As mentioned earlier, the questions addressed to the representatives of authorities, were mainly focused on their willingness to get involved in different parts of the cooperation between mobility stakeholders. Figure 15 presents the results of the corresponding questions.

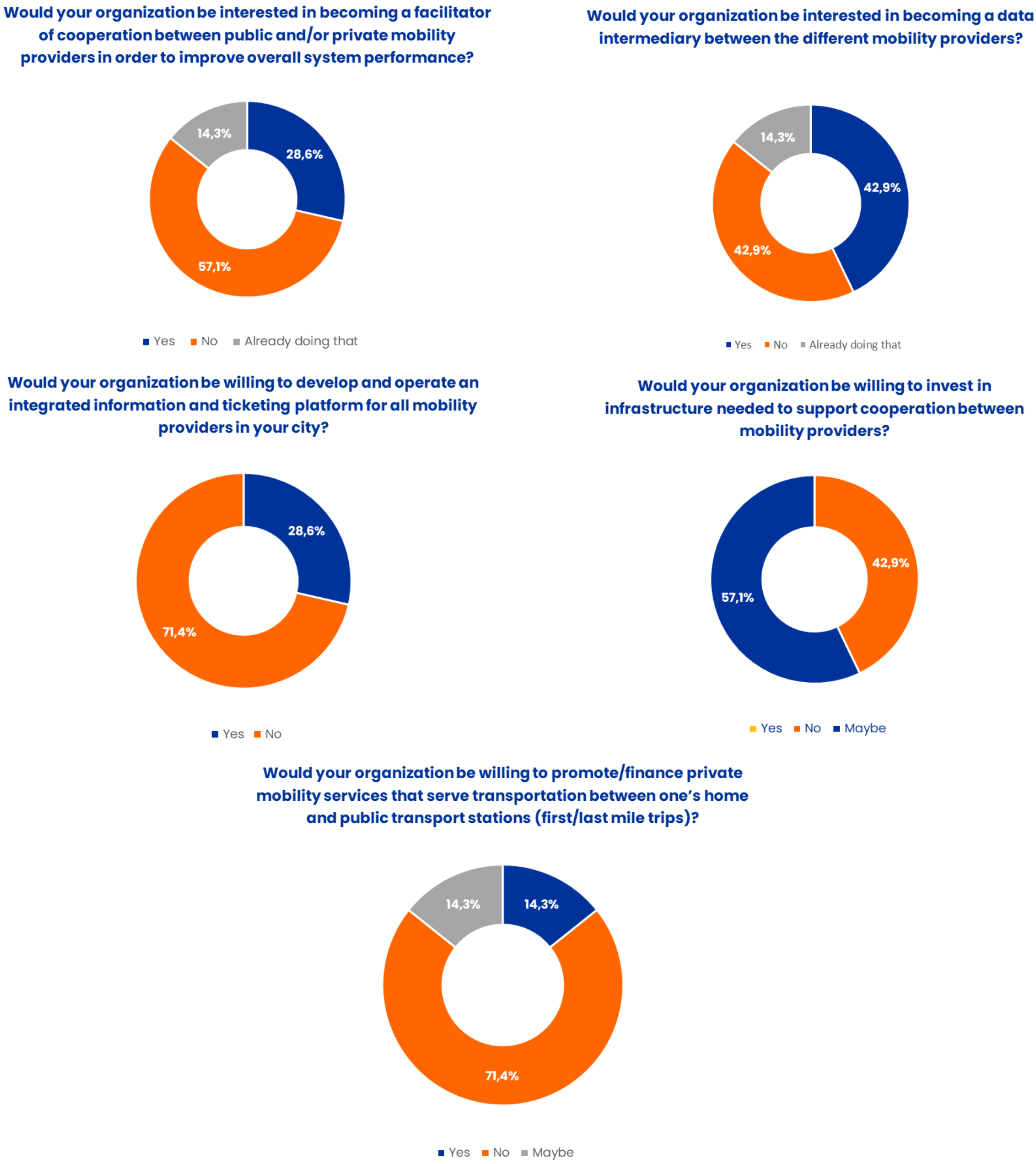

Figure 15. Authorities' willingness to get involved in different parts of cooperation between mobility providers

By observing Figure 15, one can easily conclude that the authorities are not particularly willing to take on the burden of such initiatives. The majority of representatives stated that they would not wish to become a facilitator of cooperation between public and/or private mobility providers, nor to develop and operate an integrated information and ticketing platform. The majority further stated that they are not willing to promote or finance private mobility services for the first/last mile trips from one's home to public transport stations. On the other hand, a more positive attitude towards the possibility of becoming a data intermediary between different mobility providers or in investing in infrastructure needed to support cooperation between mobility providers can be observed.

Regarding their willingness to regulate private vehicle usage, authorities appear more inclined. According to Figure 16 though, prioritization and pricing schemes attract much more interest than imposing permit schemes. It is also clear that authorities are not generally willing to impose any of the above-mentioned schemes to mobility providers.

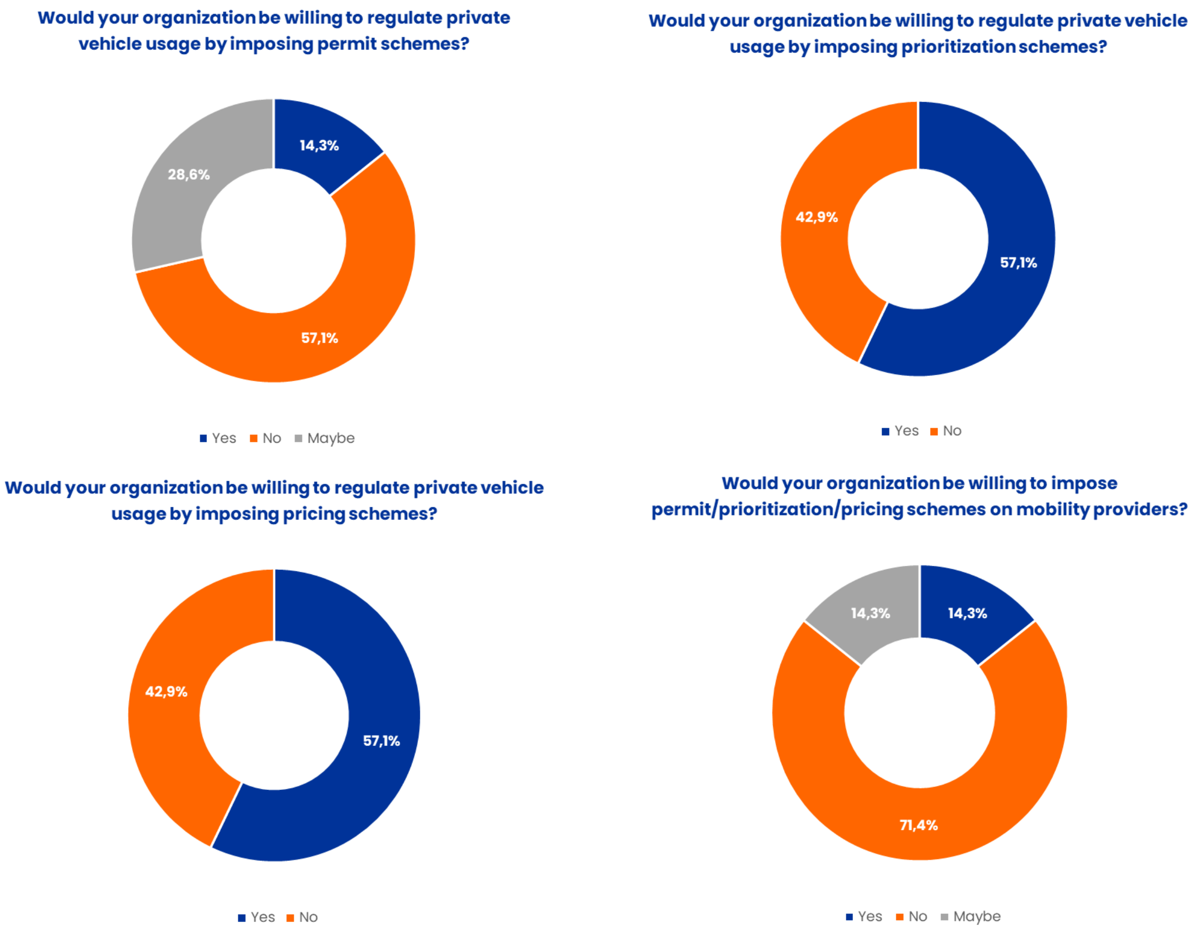

Figure 16. Authorities' willingness to regulate private vehicle usage through permit/pricing/prioritization schemes

Afterwards, the representatives of the authorities were asked to give some insights regarding cooperation and competition. A significant number of them believe that competition between mobility operators harm the overall network efficiency in their city. They use the examples of overlapping bus lines, conflicts between buses and bicycles in bus lanes, priority at traffic lights for the regularity of buses and the development of intermodality around stations. Authorities are divided in whether the introduction of pricing regulations for mobility companies (e.g., extra tax if a mobility operator has pickup & drop-off points next to public transportation stations, tolls, etc.) could improve the mobility system of their city and eliminate drawbacks from competition of mobility companies. Some are sceptical about the fairness details behind this approach but do believe that pricing regulations may improve the overall system, while others suggest that permit schemes are more suitable for preventing the cluttering of the public space. The introduction of operating & regulating policies for mobility companies such as specific parking zones and operating hours, tradable credit schemes etc., is also widely accepted as a way for improving the mobility system. However, even though there is a certain eagerness on the part of authorities to introduce such policies, the usual problem that they come up against, is that initiatives of this kind usually go beyond the remit of a single body.

Moreover, in principle, government agencies do not want to interfere in commercial activities and prefer to let the markets regulate themselves, as evidenced by their little intention to provide subsidies to mobility companies to facilitate and promote their cooperation (Figure 17).

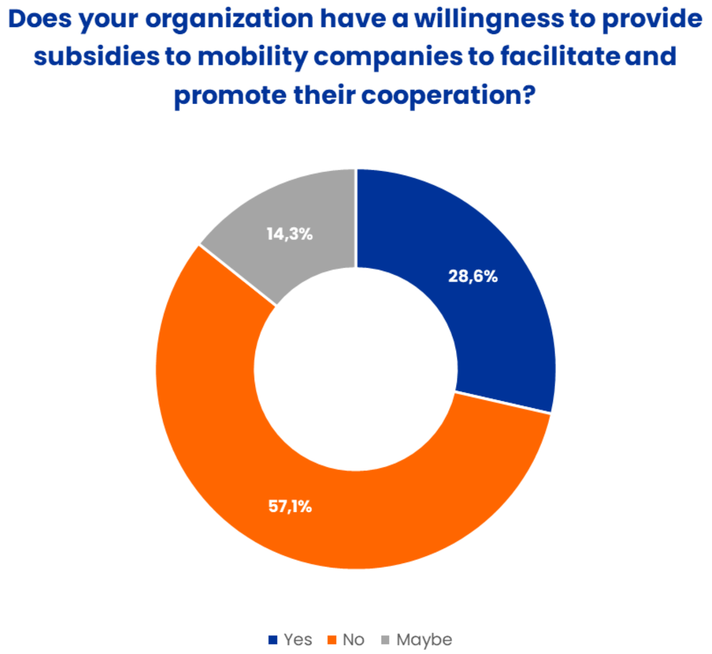

Figure 17. Authorities' willingness to provide subsidies to mobility companies in order to facilitate and promote their cooperation

4 Conclusions

In this deliverable, we formulate the problem of competition of urban mobility providers in multi-actor settings. We assume that authority regulations can push mobility operators toward fair competition and cooperation. We discuss about the objectives that we want to reach and KPIs that can help evaluate solutions. Different cooperation schemes are presented and discussed. A big part of this report is dedicated to network equilibrium modelling in multi-actor settings. We describe different modelling approaches and components and conclude that the problem is often covered from two perspectives: strategic economic modelling and operational modelling. Then, we discuss the cases where the influence of the competition on main KPIs was studied. After, we present the schemes that have been already envisioned to improve the externalities of competition. It is interesting to notice that most of the proposed strategies can be classified as centralised, which is not surprising, as regulating a competitive market usually implies common rules (regulations) stated by the local authorities. Introducing more decentralised approaches is a major challenge, as it requires designing completely new settings for the regulation.

Next, we present the results of a survey conducted among mobility actors of DIT4TraM pilot cities and other cities and regions within the EU in order to study their attitudes towards various issues of competition and cooperation. The analysis of the results of this survey showed some interesting takeaways about the differences in the operation and motivation behind private and public organizations. As expected, it became clear that public organizations are more interested in socio-political implications of mobility issues while private ones are mainly concerned with profit and their financial well-being. Therefore, the respective incentives could lead these organizations to cooperate with each other. The cooperation schemes that emerged as the most likely are those based on integrated transport services, resources sharing and data exchange, although the unlimited availability of data seems to be an issue for some private companies. In any case most stakeholders believe that overall regulations are necessary to foster collaborations between transport operators. Authorities however, do not appear generally willing to take on the burden of aiming to improve collaborations amongst mobility actors. They only keep a positive attitude towards the possibility of becoming a data intermediary between different mobility providers or investing in infrastructure. In general, they prefer regulations that do not interfere with commercial activities, which is why they also appear more willing to regulate the use of private vehicles.

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Appendix A - Questionnaire

DIT4TraM - Stakeholders' Intention to Get Involved in Fair Cooperation Schemes

This survey is conducted as part of the DIT4TraM project. The objective is to identify the most critical situations when mobility stakeholders perceive conflicting interests with other stakeholders, better understand their expectations, and the current technological and organizational processes used to improve cooperation.

Personal Details

Name: ______________________ Surname: ______________________________

E-mail: _____________________ Organization: ____________________________

Role inside the organization: ____

Organizational Priorities

1. How important is:

	Not important at all				Very important
• transportation system's efficiency for your organization?	1	2	3	4	5
• traffic safety for your organization?	1	2	3	4	5
• accessibility and social equity for your organization?	1	2	3	4	5
• environmental sustainability for your organization?	1	2	3	4	5
• having profit for your organization?	1	2	3	4	5
• improving your organization's financial viability and reducing operational cost?	1	2	3	4	5
• passenger satisfaction/loyalty for your organization?	1	2	3	4	5

2. Sort the following priorities that would motivate your organization to participate in a cooperation scheme, from the most important (1) to the least important (7).

___ Improving transportation system's efficiency (e.g., 1, if the most important)
___ Improving traffic safety
___ Improving environmental sustainability
___ Improving accessibility and social equity
___ Maximizing profit
___ Reducing operational costs
___ Improving organizations' financial viability
___ passenger satisfaction/loyalty

3. Which of the following categories most suits the role of your organization? (Check one)

☐ Public Operator (continue to section "Public Sector")
☐ Private Operator (go to section "Private Sector")
☐ Industry - Service Provider (go to section "Private Sector")
☐ SME (go to section "Private Sector")
☐ Public Authority (go to section "Authorities")

Public Sector

4. Would your organization/company consider cooperating with other public and private transport providers in a fair way on improving overall system performance?

☐ Yes ☐ No ☐ Maybe

5. If yes, in what fields would you be willing to cooperate? (You can check more than one)

☐ Data exchange
☐ Pricing
☐ Common payment systems
☐ Integrated transport services
☐ Other (please explain):____

6. Which organizations or companies would you consider cooperating with?

____

____

7. If not, why? (You can check more than one)

☐ No benefit for your organization
☐ Cooperation would not be fair
☐ Companies have conflicting interests
☐ Other (please explain):____

8. Sort the following cooperation conditions from the most important (1st) to the least important (5th) in the basis of a Public-Private Partnership (PPP).

☐ Fair profit allocation, proportional to the contribution of each side	1	2	3	4	5
☐ Fair allocation of operational cost	1	2	3	4	5
☐ Fair market share allocation	1	2	3	4	5
☐ Transparent data sharing	1	2	3	4	5
☐ Fair access to the decision making	1	2	3	4	5

9. Can you identify regulatory drawbacks that hold your organization/company back from cooperating with the private sector? If yes, please elaborate.

____

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10. Can you identify practices that you consider unfair in today's market? If yes, please elaborate.

____

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____

11. What is the level of digitalization and new technologies' incorporation of your organization/company? (1 – the highest, 5 – the lowest)

1	2	3	4	5
○	○	○	○	○

12. How much does your organization/company rely on real-time or historical demand data, weather forecasting or special events data to make decisions? (1 – highly relies, 5 – doesn't rely)

1	2	3	4	5
○	○	○	○	○

13. Would your organization/company be willing to make their data available to everyone? (Check one)

□ Yes
□ No
□ Under constraints/under specific form (aggregated data)
□ Data is already available to everyone

14. If not, why?

_ _

_ _

15. Would your organization/company be willing to exchange their data with private companies to optimize overall system performance in a fair cooperation scheme?

□ Yes
□ No
□ Under constraints/under specific form (aggregated data)
□ Data is already being exchanged with private sector
□ Data is already available to everyone

16. If not, why?

_ _

_ _

17. What would motivate your organization/company to participate in data exchange schemes?

_ _

_ _

_ _

_ _

18. Are there any specific data that your organization/company would like to have access to? If yes, please elaborate.

_ _

_ _

_ _

_ _

19. Is your organization/company currently impacted by competition with other public and/or private companies?

☐ Yes
☐ No
☐ Not sure

20. If yes, how?

----

21. What is the impact of your competition with other organizations/companies on the overall mobility system? On clients?

Positive impact:

Negative impact:

----

22. Do you think that there is a need for overall regulations to foster collaborations between transport operators, e.g., space allocation rules (operating zones, parking spots, etc.), pricing strategies (charges or rewards)?

☐ Yes
☐ No
☐ Not sure

23. If yes, please elaborate.

----

24. Can the participation in the sharing of resources (fleet, parking spots, etc.) within several public and/or private organizations/companies have an impact on your business?

☐ Yes, positive impact
☐ Yes, negative impact
☐ No
☐ Not sure

25. If yes, please elaborate.

----

26. Which benefits would motivate your organization/company to participate in the allocation/sharing of resources?

____

____

____

27. How the introduction of pricing regulations from the local authorities (extra tax if a mobility operator has pickup & drop-off points next to public transportation stations, tolls, etc.) can influence your business?

____

____

____

28. Which benefits would motivate your organization/company to accept pricing regulations?

____

____

____

29. How the introduction of operating & regulating policies from the local authorities (specific parking zones, operating hours, tradable credit schemes, etc.) can influence your business?

____

____

____

30. Which benefits would motivate your organization/company to accept new operating policies?

____

____

____

31. In the case of cooperation with other organizations/companies, which cooperation scheme would you prefer?

☐ Decentralized (local optimizers)
☐ Distributed (local optimizers that exchange information)
☐ Centralized (one optimizer)
☐ Other (please explain): ____

Private Sector

32. Would your company consider cooperating with public authorities/organizations in a fair way on improving overall system performance?

☐ Yes ☐ No ☐ Maybe

33. If yes, in what fields would you be willing to cooperate? (You can check more than one)

☐ Data exchange
☐ Pricing
☐ Common payment systems
☐ Integrated transport services
☐ Other (please explain): ____

34. Which public organizations would you consider cooperating with?

____

____

35. If not, why? (You can check more than one)

☐ No benefit for your company
☐ Cooperation would not be fair
☐ Companies have conflicting interests
☐ Other (please explain): ____

36. Sort the following cooperation conditions from the most important (1) to the least important (5) in the basis of a Public-Private Partnership (PPP).

___ Fair profit allocation, proportional to the contribution of each side (e.g., 1, if the most important)
___ Fair allocation of operational cost
___ Fair market share allocation
___ Transparent data sharing
___ Fair access to the decision making

37. Would your company consider cooperating with private organizations in a fair way on improving overall system performance?

☐ Yes ☐ No ☐ Maybe

38. If yes, in what fields would you be willing to cooperate? (You can check more than one)

☐ Data exchange
☐ Pricing
☐ Common payment systems
☐ Integrated transport services
☐ Other (please explain): ____

39. Which private companies would you consider cooperating with?

____

____

40. If not, why? (You can check more than one)

□ No benefit for your company
□ Cooperation would not be fair
□ Companies have conflicting interests
□ Other (please explain): ____

41. Sort the following cooperation conditions from the most important (1) to the least important (5) in the basis of a cooperation between private companies.

___ Fair profit allocation, proportional to the contribution of each side (e.g., 1, if the most important)
___ Fair allocation of operational cost
___ Fair market share allocation
___ Transparent data sharing
___ Fair access to the decision making

Can you identify regulatory drawbacks that hold your company back from cooperating with the private sector? If yes, please elaborate.

____
____
____
____
____
____

42. Can you identify practices that you consider unfair in today's market? If yes, please elaborate.

____
____
____
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43. What is the level of digitalization and new technologies' incorporation of your company? (1 – the highest, 5 – the lowest)

1	2	3	4	5
○	○	○	○	○

44. How much does your company rely on real-time or historical demand data, weather forecasting or special events data to make decisions? (1 – the highest, 5 – the lowest)

1	2	3	4	5
○	○	○	○	○

45. Would your company be willing to make their data available to everyone? (Check one)

□ Yes
□ No
□ Under constraints/under specific form (aggregated data)
□ Data is already available to everyone

46. If not, why?

47. Would your company be willing to exchange their data with a public organization to optimize overall system performance in a fair cooperation scheme?

☐ Yes
☐ No
☐ Under constraints/under specific form (aggregated data)
☐ Data is already being exchanged with private sector
☐ Data is already available to everyone

48. If not, why?

49. Would your company be willing to exchange their data with another private company to optimize overall system performance in a fair cooperation scheme?

☐ Yes
☐ No
☐ Under constraints/under specific form (aggregated data)
☐ Data is already being exchanged with private sector
☐ Data is already available to everyone

50. If not, why?

51. What would motivate your company to participate in data exchange schemes?

52. Are there any specific data that your company would like to have access to? If yes, please elaborate.

53. Do you feel that your company currently suffers from competition with other transportation companies that can harm your business?

☐ Yes
☐ No

54. If yes, please elaborate what is the impact of the competition on your company.

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55. Do you feel that your company currently suffers from competition with other transportation companies that can harm the overall network efficiency (congestion level, CO_2 emissions, etc.) and clients?

☐ Yes
☐ No

56. If yes, please elaborate.

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57. Do you think that there is a need for overall regulations to foster collaborations between transport operators, e.g., space allocation rules (operating zones, parking spots, etc.), pricing strategies (charges or rewards)?

☐ Yes
☐ No

58. If yes, please elaborate.

---

59. Can the participation in the sharing of resources (fleet, parking spots, etc.) within several public and/or private organizations/companies have an impact on your business?

☐ Yes, positive impact
☐ Yes, negative impact
☐ No
☐ Not sure

60. If yes, please elaborate.

---

61. Which benefits would motivate your company to participate in the allocation/sharing of resources?

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____

____

62. How the introduction of pricing regulations from the local authorities (extra tax if mobility operator has pickup & drop-off points next to public transportation stations, tolls, etc.) can influence your business?

____

____

____

63. Which benefits would motivate your company to accept pricing regulations?

____

____

____

64. How the introduction of operating & regulating policies from the local authorities (specific parking zones, operating hours, tradable credit schemes, etc.) can influence your business?

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____

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65. Which benefits would motivate your company to accept new operating policies?

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____

66. In the case of cooperation with other companies, which cooperation scheme would you choose?

◻ Decentralized (local optimizers)
◻ Distributed (local optimizers that exchange information)
◻ Centralized (one optimizer)
◻ Other (please explain): ___________________________________

Authorities

67. Would your organization be interested in becoming a facilitator of cooperation between public and/or private mobility providers in order to improve overall system performance?

☐ Yes
☐ No
☐ Maybe (Please elaborate): ____________________

68. Would your organization be interested in becoming a data intermediary between the different mobility providers?

☐ Yes
☐ No
☐ Maybe (Please elaborate): ____________________

69. Would your organization be willing to develop and operate an integrated information and ticketing platform for various mobility providers in your city?

☐ Yes
☐ No
☐ Maybe (Please elaborate): ____________________

70. Would your organization be willing to invest in infrastructure needed to support cooperation between mobility providers?

☐ Yes
☐ No
☐ Maybe (Please elaborate): ____________________

71. Would your organization be willing to promote/finance private mobility services that serve transportation between one's home and public transport stations (first/last mile trips)?

☐ Yes
☐ No
☐ Maybe (Please elaborate): ____________________

72. Would your organization be willing to regulate private vehicle usage by imposing permit schemes?

☐ Yes
☐ No
☐ Maybe (Please elaborate): ____
____
____
____
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73. Would your organization be willing to regulate private vehicle usage by imposing prioritization schemes?

☐ Yes
☐ No
☐ Maybe (Please elaborate): ____
____
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____
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74. Would your organization be willing to regulate private vehicle usage by imposing pricing schemes?

☐ Yes
☐ No
☐ Maybe (Please elaborate): ____
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75. Would your organization be willing to impose permit/prioritization/pricing schemes on mobility providers?

☐ Yes
☐ No
☐ Maybe (Please elaborate): ____
____
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____

76. Have you experienced situations where competitions between mobility operators harm the overall network efficiency in your city? (emissions, safety, congestion, accessibility, flexibility, cost, etc.)

☐ Yes

☐ No

77. If yes, please elaborate.

____
____
____

78. Can the introduction of pricing regulations for mobility companies (extra tax if a mobility operator has pickup & drop-off points next to public transportation stations, tolls, etc.) improve the mobility system in your city and eliminate the drawbacks from the competition of mobility companies? How?

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79. Can the introduction of operating & regulating policies for mobility companies (specific parking zones, operating hours, tradable credit schemes, etc.) improve the mobility system in your city and eliminate the drawbacks from the competition of mobility companies? How?

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80. Can the introduction of other policies for mobility companies help to eliminate the drawbacks from their competition? Which policies? How can it help?

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81. Are there any obstacles that prevent your organization from introducing new policies for mobility companies?

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82. Does your organization have a willingness to provide subsidies to mobility companies to facilitate and promote their cooperation?

☐ Yes
☐ No
☐ Not sure

83. If not, why?

DIT4TraM

Distributed Intelligence & Technology
for Traffic & Mobility Management

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