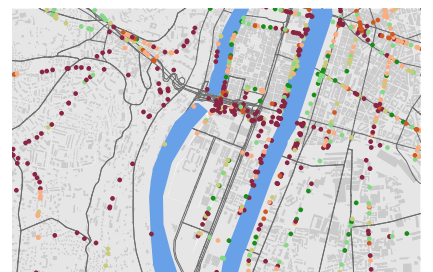
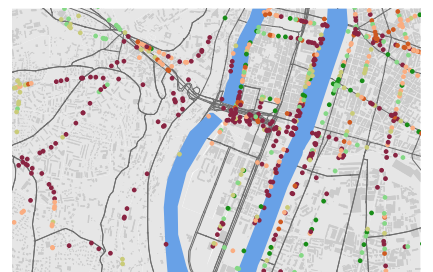


Shared Mobility Simulations for Lyon



Case-Specific Policy Analysis

Shared Mobility Simulations for Lyon



Case-Specific Policy Analysis

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International Transport Forum
2, rue André Pascal
F-75775 Paris Cedex 16
contact@itf-oecd.org
www.itf-oecd.org

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Executive summary

What we did

This report examines how new shared services could change mobility in Lyon. It presents simulations for five different scenarios in which different shared transport options replace privately owned cars in the Lyon metropolitan area. The simulations offer insights on how shared mobility can reduce congestion, lower transport greenhouse gas (CO₂) emissions and free public space. The analysis also looks at quality of service, cost and citizens' access to opportunities. Further, the report examines the interaction of shared mobility services with mass public transport and the optimal operational conditions for the transition.

Shared mobility in this study refers to optimised on-demand transport services that are shared among users. The report is part of a series of studies on shared mobility in different urban and metropolitan contexts. This is the first International Transport Forum (ITF) report on shared mobility which also explores deployment of the shared services through carpooling. Previous ITF studies have shown that shared mobility has the potential to provide citizens with a flexible and comfortable transport mode while reducing congestion and CO₂ emissions.

What we found

The current mobility demand in the Lyon metropolitan region could be met almost entirely by shared mobility and present public transport systems, reducing private vehicles to only 5% of the modal share, all of which would be used for carpooling.

A scenario where carpooling is introduced as an additional shared mobility mode would result in an 87% reduction in the vehicle fleet, as some households would retain their cars. Even then, the total distance driven, CO₂ emissions and congestion would still be reduced by 54%, 50%, and 48% respectively. If only 20% of private car trips were replaced by shared modes – a plausible scenario according to the stated preference survey – vehicle-kilometres would fall by 11% and CO₂ emissions by 12%.

Introducing shared mobility would help optimise the use of existing bus and rail-based networks, including rail, metro and light rail transit (LRT). The public transport network in the Lyon metropolitan region is extensive and diverse. Rail-based solutions within the city centre provide efficient links to suburban areas and the core bus network covers a significant part of the bus demand. Were the city to replace underused and inefficient bus routes with a taxi-bus system, this and other shared mobility services could become feeders to public transport, reducing private car use by 20% and resulting in a 12% reduction of CO₂ emissions and a 16% reduction in congestion.

A survey for this study found that most citizens are willing to use shared modes for direct trips or to access high capacity public transport. The majority of current public transport users are willing to pay a higher ticket price for the new service and most car users expect shared mobility fares to be lower than the current cost of using a private car.

What we recommend

Integrate shared mobility services into the Lyon metropolitan region transport system

Shared on-demand mobility services could provide significant benefits to the Lyon metropolitan region by reducing CO₂ emissions, congestion and the need for parking space. Shared mobility would also result in better access to opportunities for citizens, and make access more equitable for inhabitants of areas that currently lack connection to public transport.

Create pilot projects and public awareness campaigns to achieve scale of service

The development of pilot programmes and targeted public information campaigns can create traction among potential users and help avoid and overcome user resistance. Pilots may include consumer testing programmes of new mobility service, including carpooling.

Shared mobility services should be scaled for effectiveness

Reductions in CO₂ emissions and congestion are higher when larger portions of car users shift to new shared modes. High levels of vehicle occupancy are key to generating effective geographical coverage at affordable costs for users. Policy makers should take this into account when selecting the types of vehicles to deploy and the fleet size for each shared mobility mode. In the case of low emission zones, adequate infrastructure should be installed in advance to limit congestion at park-and-ride stations, facilitate traffic flow, and provide safe and easy access to encourage ridership.

Integrate shared services as feeders to public transport and make taxi-buses part of the bus network

New shared mobility services can improve the performance of the existing public transport system if properly integrated. Shared modes can act as feeder services to the metro, LRT system and the rail network and lead to increased ridership. They can act as feeder services for selected higher capacity metro and LRT stations with no change to the existing infrastructure. Taxi-buses should cooperate with conventional buses of the core network or the future bus transit system, rather than substitute them.

Ensure that transport infrastructure is adapted to meet the growing demand

Shared mobility is only as effective as the infrastructure that supports it. Drop-off and pick-up points at public transport stations must sufficiently support the rise in passenger numbers. Additional system capacity may also be required for the different public transport modes to accommodate the increased ridership. Station layouts may need to be redesigned so that good access is maintained for the users of non-motorised modes and the specific needs of the shared mobility services are properly integrated. Public-private partnerships can enable the planning and development of infrastructure and the design of services towards meeting sustainable goals.

Create legal and regulatory frameworks that encourage the uptake of shared mobility services to deliver societal benefits

A shift to shared mobility requires the alignment of policy tools such as pricing, regulation and licensing, concessioning, land use and infrastructure design to provide a stable and predictable market for new shared mobility services and to maximise the potential benefits. Introduction of shared mobility services will require continuous monitoring of performance in order to adjust regulations or policies where outcomes diverge from objectives.

Introduction

Today's era is marked by an explosion of technological disruptions. The growth of the sharing economy, in which people exchange goods and services, is one of the most noticeable disruptions and has the potential to drastically change the way urban transport is organised and delivered. This, together with ubiquitous digitalisation that allows for the efficient matching of demand and supply, has led to the on-demand shared transport paradigm currently taking over urban areas.

Optimised sharing solutions have the potential to provide citizens with a more flexible and comfortable public transport alternative than conventional public transport. It could encourage citizens to make a shift from private cars to more sustainable solutions, leading to a reduction in congestion, social exclusion and road accidents, to more efficient use of public space, and to better air quality. This study examines how the optimised sharing of transport services can transform mobility in the Lyon metropolitan region (LMR) while promoting public transport integration and preserving non-motorised modes.

In recent years, the population of the LMR has grown. More people are commuting to work and to places of education (Lahi, 2019). The rising population and the region's decarbonisation targets have spurred the Grand Lyon metropolitan authority to establish a medium-term plan to reduce greenhouse gas (CO₂) emissions before 2030 (Grand Lyon, 2017). Transport plays an important role in the plan, whether it be through improved infrastructure and services or by promoting cleaner, more active public transport options. In the coming years, Grand Lyon will continue improving and expanding the public transport system coverage and performance, and the cycling and pedestrian infrastructure. It will also apply demand management measures to encourage the shift from private car to public transport. However, some low-density areas in the LMR lack good public transport coverage; where it is provided, the service's reliability and frequency are often insufficient to serve currently passengers and attract more (Sytral, 2017).

The rapid evolution of technologies, societal trends and business models creates a challenge for authorities who are willing to encourage a shift from private cars to shared modes. Developing a regulatory environment for the successful uptake of the new modes is a challenge. However, it may be the element that bridges the gap of accessibility requirements in lower-density communities that need to move frequently to the urban centre and are largely dependent on private cars (Sytral, 2017). This report assesses the impact of shared services on key performance indicators based on simulations of various mobility scenarios in the presence of the new modes. It aims to assist authorities in the design of future services and regulations to ensure their effective integration into the transport system.

The ITF Shared Mobility Model simulates daily travel for a hypothetical shared mobility system. Previous ITF Corporate Partnership Board reports presented the potential impacts of new shared urban mobility solutions leveraged by digital connectivity in the city of Lisbon (ITF, 2015, 2016, 2017c). The results of the simulations showed that a large-scale introduction of the new shared modes would lead to strong a reduction in the required vehicle fleet, emissions and congestion while improving equity of access, aiding the urban transport sector in achieving its decarbonisation objectives and promoting the other pillars of sustainability. This work was expanded and tested in other metropolitan areas around the world: Helsinki (ITF, 2017b), Auckland (ITF, 2017a) and Dublin (ITF, 2018). The work showed interesting and comparable

impacts, and illustrated the opportunities and challenges that shared mobility presents for cities in the near future.

The modelling tool used to assess the impact of shared mobility combined qualitative and quantitative approaches which included a micro-simulation model and a stated preference survey to identify potential users. The proposed shared services are shared taxis, taxi-buses and carpooling. The three modes could fully or partially replace current motorised road transport alternatives (cars, motorcycles, taxis and buses) and serve as a feeder to rail-based public transport systems (rail, metro and light rail transit, (LRT)). The first two kinds of services are on-demand, dynamically dispatched, fleet-owned, and operated by a centralised entity tested in previous reports: shared taxis and taxi-buses.

Shared taxis provide a door-to-door service by a four- to six-seater vehicle, moving along trajectories optimised in real-time with small detours for passenger boarding and alighting. Taxi-buses provide a street-corner-to-street-corner service that requires a 30-minute advanced reservation and direct trips in a minibus of eight to 16 people along dynamically defined routes.

This report also investigates a third service: carpooling. Carpooling services are organised for drivers through a shared mobility toolkit. The region provides the necessary infrastructure allowing carpoolers to meet up. It designates parking lots at which passengers may meet with car owners. The passengers are then dropped off at designated stopping areas located no further than one kilometre from their final destination. This system is designed mainly for commuting travel and uses other shared mobility services as a safety net if matching procedures fail. This new mode is incorporated into the mobility toolkit under Mobility as a Service (MaaS).

Prior to the simulations, the LMR transport users' preferences regarding the proposed shared modes were compared to the existing urban and suburban transport options. The data was collected through a stated preference survey. The analysis of the data included the identification and quantification of the most important attributes of the new modes and socio-demographic characteristics of the users that influence mode choice. This enabled the identification of potential early adopters of the new services. The information can be used to design new modes of transport that are better tailored to potential users' needs, increasing the likelihood that the desired modal shift is achieved. It also facilitates the development of targeted awareness campaigns that inform users of the benefits of the new transport alternatives. The detailed attributes of the service provided by shared modes are adjusted to match the reported users' preference (e.g. maximum waiting time, maximum detour time).

The micro-simulation model reproduces the daily mobility patterns and the interactions between users and shared mobility modes in an urban transport network. The agent-based simulation manifests itself in a dynamic, optimised matching of demand and supply under minimal detour distances and travel time constraints. The model enables the exploration of different transport scenarios that preserve the behavioural preferences of the citizens. This provides insights on how the potential new modes will perform in terms of quality of service, productive efficiency and cost competitiveness; and their potential impact on mobility, accessibility, environment, and public space use in the LMR.

The scenarios tested include a reference full-adoption scenario and partial-adoption scenarios. In the reference scenario, the existing motorised transport alternatives (private car and buses) are completely substituted with shared mobility services. In partial-adoption scenarios, only certain trips by motorised modes are substituted, conditioned by the origin and destination, mode, and the value of the utility of different modes for a given transport user. While the reference scenario represents the maximum potential of shared mobility, the partial-adoption scenarios facilitate the investigation of the impact of gradually deploying the services and the impact of specific measures adoption.

Modelling framework and shared modes specification

This section presents the ITF shared mobility modelling framework and provides a detailed description of the simulation model and shared modes specifications. The project description was adapted from a previous ITF study on shared mobility performance for Auckland (ITF, 2017a).

The ITF shared mobility modelling framework was developed from five main building blocks and study stages as presented in Figure 1. The first block addressed the characterisation of the study area. This characterisation included the spatial definition of the study area and its land-use characteristics; the available transport infrastructure and services (road network and public transport services), and the resulting transport performance by spatial division (grid), origin-destination (OD) pair and transport mode; and the analysis of mobility using the Lyon metropolitan region from the most recent regional travel survey (Sytral, 2014). The elements of this block are discussed in the section “A characterisation of the Lyon metropolitan area”.

All the data from the first building block were used to estimate a revealed preference mode choice model as the final input to create a synthetic mobility dataset. The synthetic population and its socio-demographic characteristics were based on 2015 census data from France (INSEE, 2015) and results from the 2014 Household Travel Survey (Sytral, 2014). The characteristics were expanded to the total population by generating synthetic households’ compositions with similar mobility profiles as the Household Travel Survey sample. The trip patterns of each representative of the synthetic population and their spatial distribution were based on the travel survey revealed preference data. The model generated the mobility of these individuals constrained to their generated residential location, land-use distribution in the study area, and the transportation network performance for the generated transport modes. The estimated mode choice model produced the probabilities used to assign a transport mode for each trip. The development of this stage is described in the section “Modelling current travel demand”.

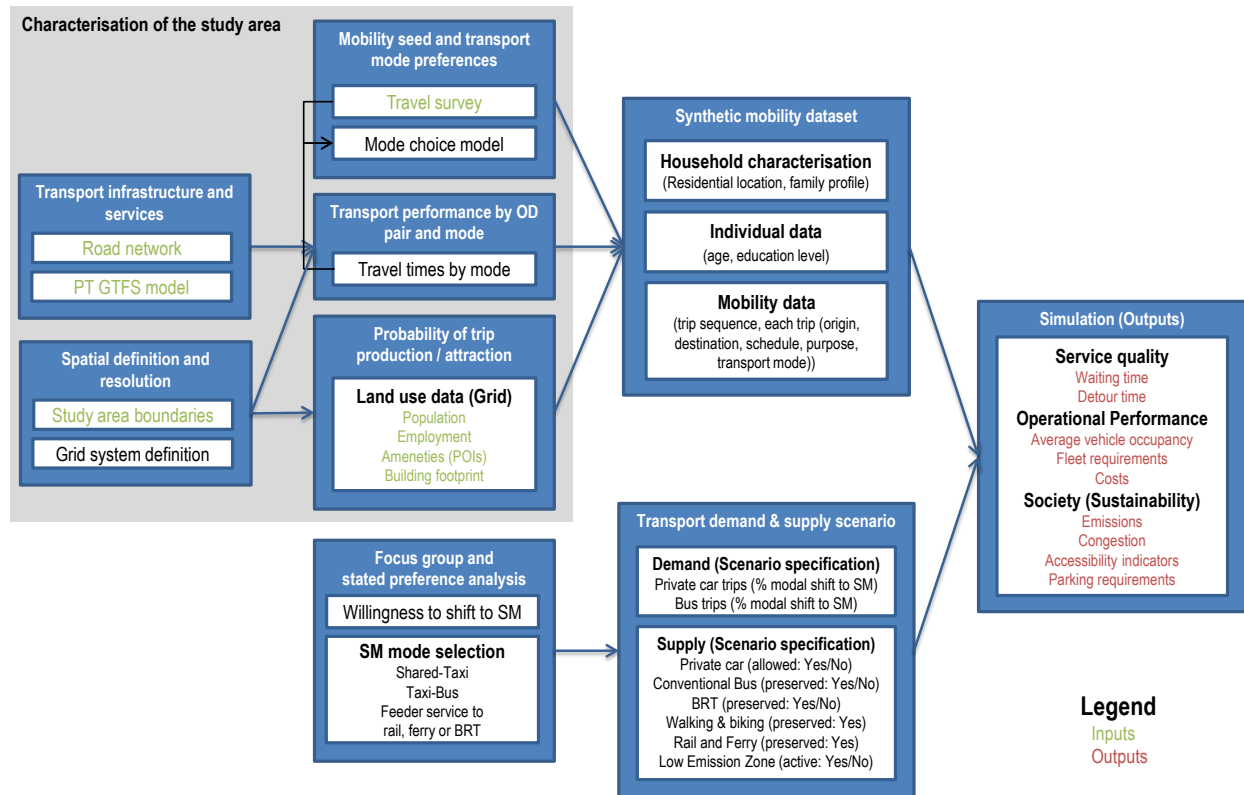
The next stage of the study collected information from a web-based revealed and stated preference survey to identify the city citizens’ willingness to adopt shared mobility (described in the section “Potential users of shared mobility”). The survey revealed the most important attributes of the shared modes and social-demographic characteristics of the users’ influencing mode choice, as well as the calibration of a new mode choice model. The sample size of the web-based survey was increased through the recruitment of additional respondents. The additional information collected was used to identify the market segments of early adopters and rank the willingness of current private motorised transport (car, motorcycle or taxi) and bus users to switch to shared mobility modes. If a user was willing to switch to a shared mode, the calculated mode choice probabilities determined which of the two the user was most likely to choose for each trip.

The ITF and the Grand Lyon metropolitan authority then established a set of eleven transport supply scenarios with different adoption levels of the shared modes and remaining shares of private car and bus users, based on the focus group results. These scenarios are described in detail in the section “Setting the shared mobility scenarios”.

The synthetic mobility dataset and the different transport demand and supply scenarios were then tested in the ITF shared mobility simulation model. The outputs for each tested scenario included measures of service quality, operation performance and sustainability. These results are discussed in the section “Impact of shared mobility”.

The subsections below present the specifications for the different shared modes and a detailed description of the simulation model.

Figure 1. ITF’s shared mobility modelling framework



Notes: PT- public transport; OD – origin-destination; SM – shared mobility.

Source: ITF (2017a).

Shared modes specifications

Three shared transport services were used to assess the impact of shared mobility services: shared taxis, taxi-buses and carpooling. The new modes can fully or partially replace current motorised modes and serve as a feeder to existing rail lines. A feeder service is a pre-booking system with booking rules and accessibility constraints similar to those of taxi-buses. The feeder services serve rail trips for which one station is within walking distance from either origin or destination. This means that the entire trip would have one transfer and include two legs: one by a shared mode serving only one end of the trip and a second by rail. An origin-destination (OD) pair poorly served at both ends leads to a direct taxi-bus or a shared taxi service.

Shared taxis are an on-demand door-to-door service with seating capacity for up to six people (Figure 2). They can be booked in real-time and move along dynamically optimised trajectories with detours and travel times matching predefined constraints.

Taxi-buses provide a street-corner-to-street-corner service in a minibus with seating capacity for eight or 16 people (Figure 3). Reservations must be made at least 30 minutes in advance. Taxi-buses also move along dynamically optimised routes between designated stops. Both shared services offer direct trips or deliver the user to a rail station if direct rail connections are available to the destination.

Carpooling services are requested via a smartphone or a terminal. Potential drivers of a private car provide their intended departure time 15 to 30 minutes before the trip. They are registered prior to service and are notified of a pool formation and the pick-up time and location. Carpooling pick-up points can be either predetermined on-street locations indicated by a carpooling sign (Figure 4) or in dedicated parking lots. Passengers may access departure stops on foot or by car. Parking lots dedicated as pick-up zones provide free parking to carpool passengers.

Figure 2. Example of a shared taxi vehicle



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Figure 3. Example of a taxi-bus vehicle



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Figure 4. Example of a carpooling stop



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A carpool driver drops passengers at designated stations in the city centre within one kilometre of the passengers' final destinations. The driver then continues to his or her final destination, located no more than a five-minute driving time from the carpooling destination drop-off location. Walk-up access stops for carpool passengers coincide with designated taxi-bus stops or are integrated with existing public

transport stops or stations. Passengers pay the driver a cost-share comparable to a bus ticket, in the range of EUR 1 to EUR 3.

Table 1 shows the characteristics of the different types of shared services. The services were designed as alternatives to the private car, offering more flexibility, comfort and availability than the existing public bus system, while remaining more affordable than conventional taxi services. Some of the values presented in Table 1 were used as a starting point for the focus group discussion (presented in the section “Potential users of shared mobility”) and were subject to further adjustments based on the results.







Table 1. Specifications for proposed services

Mode	Booking	Access time	Maximum waiting time (depending on distance)	Maximum total time loss (depending on distance)	Vehicle type
Shared taxi	Real-time	Door-to-door	Five minutes (\leq three km), linear increase from five to ten minutes (between three and 12 km), ten minutes (\geq 12 km)	Detour time + waiting time, from seven minutes (\leq three km), up to 15 minutes (\geq 12 km)	Minivan of eight seats rearranged for six seats, with easy entry/exit
Taxi-bus	30 minutes in advance	Boarding and alighting up to 400 m away from door, at points designated in real-time	Tolerance of ten minutes from preferred boarding time	Minimum linear speed from origin to destination (15 km/h)	Minibuses with between eight and 16 seats. No standing places
Carpooling	15 to 30 minutes in advance	Walk to a carpooling stop or drive to a carpooling dedicated parking lot	Tolerance of 15 minutes from preferred departure time	ten minutes access (walking or driving) + five extra minutes waiting at stop or depot + ten minutes walking at destination	Regular private car (owned by the assigned driver)

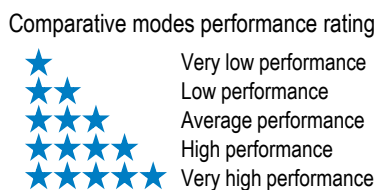
Source: Adapted from ITF (2017a).

Figure 5 compares the various performance attributes among the transport modes used in the simulation. It highlights the differences that lead to either market segmentation or change of performance when compared with currently available transport services. Shared taxis clearly present a performance profile similar to private cars, while taxi-buses and feeder services try to preserve attractive features of current public transport (e.g. price) and enhance the ones that often deter users from conventional buses (e.g. on-board time, waiting time and transfers). Carpooling services reproduce features of the private car by reducing the cost feature of daily private car use.

Figure 5. Qualitative comparison of transport modes

Service type	Service quality					
	Access	On-board time	Waiting	Transfers	Comfort	Price
Private Car 	★ ★ ★	★ ★ ★ ★	★ ★ ★ ★	★ ★ ★ ★	★ ★ ★ ★	★
Public transport 	★ ★	★	★	★ ★	★ ★	★ ★ ★ ★
Shared Taxi 	★ ★ ★ ★	★ ★ ★	★ ★ ★ ★	★ ★ ★ ★	★ ★ ★ ★	★ ★
Taxi-Bus 	★ ★ ★	★ ★ ★	★ ★ ★	★ ★ ★ ★ ★	★ ★ ★ ★	★ ★ ★
Feeder service to rail, ferry or BRT 	★ ★ ★	★ ★ ★ ★	★ ★	★ ★ ★ ★	★ ★ ★	★ ★ ★ ★
Carpooling 	★ ★ ★	★ ★ ★	★ ★ ★	★ ★ ★ ★	★ ★ ★	★ ★ ★

Legend:



Source: adapted from ITF (2017a).

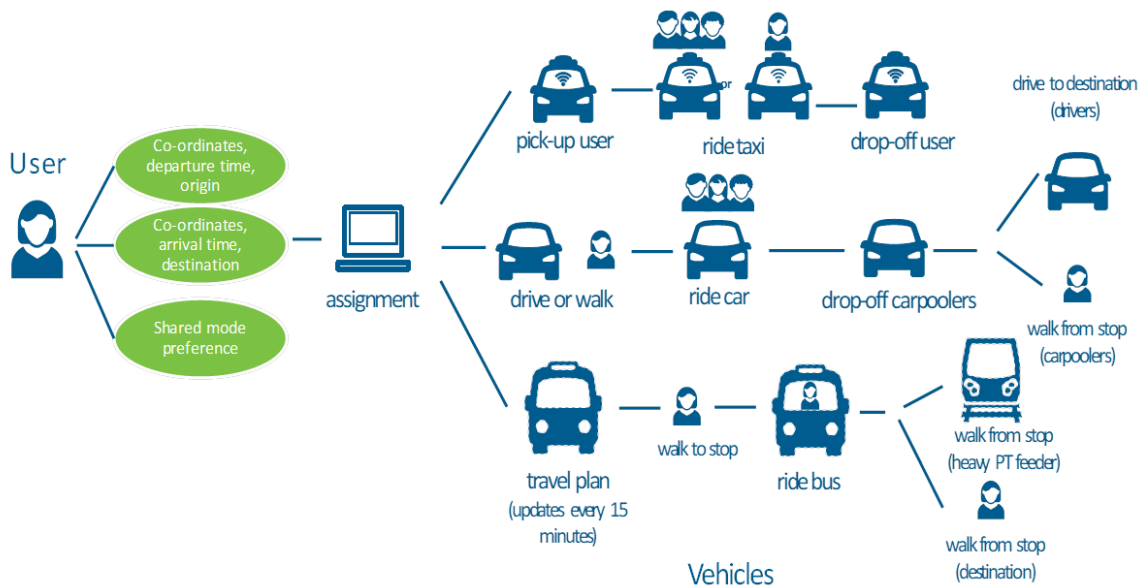
The configuration of shared services and their interaction with public transport systems is completely flexible and reconfigurable. The tested solutions do not intend to be prescriptive of what can emerge in the market or is organised by public transport authorities, but to assess the potential of like solutions that have emerged in the market (shared taxi – e.g. UberPOOL and Lyft Line; taxi-bus – e.g., Kutsuplus in Finland, and BRIDJ in the United States). Finally, carpooling tests along a city corridor identify the potential of such organised systems and mobile applications to improve the mobility of the corridor and to reduce the cost for users as well as the environmental burden of their daily mobility.

ITF shared mobility simulation model

The core of the modelling framework is an agent-based simulation model. The model has three main agents interacting in a common environment: users, vehicles and a dispatcher (Figure 6). It reproduces the daily mobility patterns in the study area for the synthetic population, matches demand and supply, and saves the trip logs for the estimation of performance indicators. Two types of shared services are considered: a door-to-door shared taxi and an on-demand bus-like system called taxi-bus.

In the simulation environment, a trip is generated when a user (or a party of users) requests a service. The mode is then assigned to the user based on the calculated mode choice probabilities. A dispatcher then matches the demand with the transport supply. If the user prefers a taxi-bus, they need to order the service 30 minutes in advance and provide the location of origin, the destination and the desired departure time. The system can generate a new route with the recent demand, allocate the clients to vehicles already under operation, or reassign this request to the shared taxi service. More specifically, the dispatcher finds the best match in taxi-bus service that warrants at least 50% occupancy (for at least part of the trip) and an average distance-based occupancy rate of greater than 25% of vehicle capacity. If the user requests a taxi-bus but there are no designated stops within the acceptable distance or not enough users to meet the 40% minimum occupancy constraints, the user is upgraded to a shared taxi at no extra fee.

Figure 6. Relation between agents in the simulation model



Source: ITF (2017a).

Shared taxi requests are handled in real-time. The dispatcher analyses each request and provides the user with the pick-up time, the vehicle licence plate, the number of clients who will share the vehicle and indicates if the user should cross the street to reduce waiting time. The model takes into account a distance-minimisation principle that applies not only to the requesting user but also to those already on route in the implicated vehicle. The dispatcher runs a local search algorithm that tries to minimise the additional travel distance generated by the new client, complying with current users' waiting time and detour time constraints. The waiting time, detour time and arrival time of the resulting trips must be within the model constraints. The constraints are calculated based on the current trip characteristics, with some variations within pre-set tolerances.

The dispatcher also controls the vehicle movements when idle, ensuring efficient vehicle movements to stations and calculating the additional fleet requirements. Whenever the car is not dispatched to a new trip, it returns to the nearest station and stays there while idle. Taxi-buses relocate from the last performed service to a departure stop of the next generated route. The shared taxi depots and taxi-bus departure stops are set across the city at predefined locations. Positioning of the taxi-bus stops is constrained by a minimum distance between stops (400 m) and the selection of the road node with greater connectivity in the neighbouring area, in order to ensure flexible routing for the vehicles, e.g. by avoiding one-way streets.

The obtained flows are attributed to each link of the road network through a dynamic traffic assignment procedure that updates travel time based on volume-capacity ratio for every five simulated minutes. The study area is divided into a grid with cells of different sizes: 1 000 m by 1 000 m, 500 m by 500 m, and 200 m by 200 m, so that the denser parts of the study area are covered with smaller cells. The origins and destinations of the generated trips are linked to the closest road network nodes.

Once the users' trip is finished, the agent representing the user leaves the simulation system and indicators are generated in a trip log so that they can be used for *ex-post* system evaluation. The model produces detailed information regarding the origins and destinations of each trip, the number of passengers boarding at each stop, arrival and departure time, waiting and access time, travel time, transfers, and associated costs. The model assumes an app-based wire payment method with no cash transactions, allowing easier, safer and faster client pick-up and drop-off.

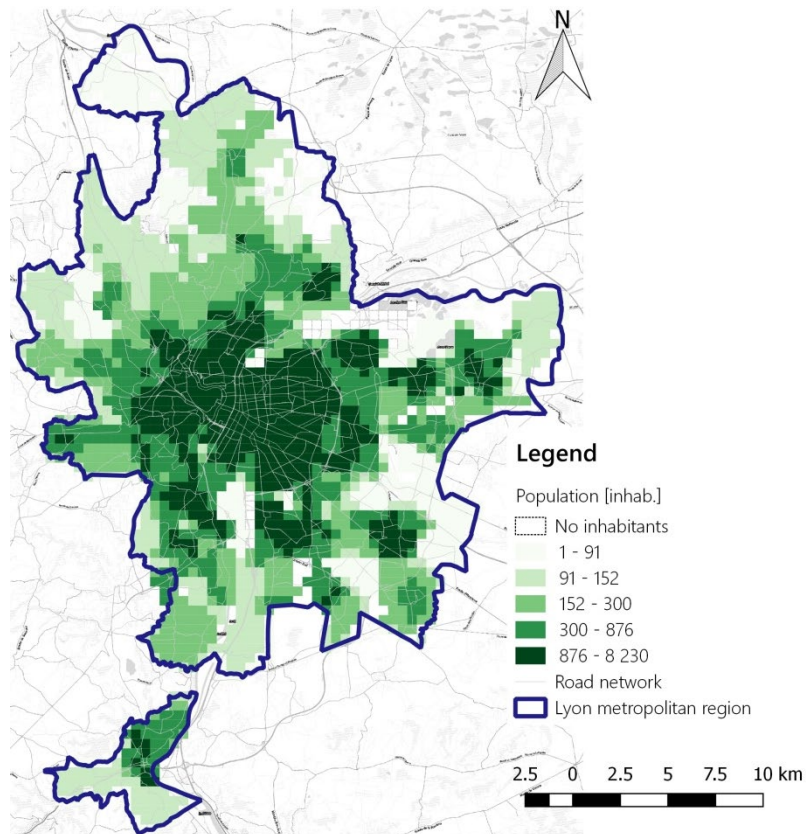
The simulation allows for the testing of the system operation, either with drivers constrained by working regulations, or by self-driving vehicles that do not need to relocate to ensure the changes of drivers' shifts. The cost estimations are different for these two options.

The simulation model provides detailed outputs from the resulting mobility throughout the day for each mobility scenario tested: passenger-kilometres (pkm); vehicle-kilometres (vkm) by mode; operational performance, including fleet requirement, routes operated, occupation levels by mode, and estimated costs; client satisfaction in terms of travel time, waiting time, detour time, average number of passengers on board by time of the day and mode; and environmental performance (CO₂ emissions). Adoption of electric fleets and their charging requirements are also included as a parameter in the model.

A characterisation study of the Lyon metropolitan region

The Lyon metropolitan region (LMR), designated administratively as Grand Lyon, spreads over a surface of about 534 km² (of which Lyon municipality constitutes 48 km²). The population of the region was 1.34 million in 2015, the census year used for this study. Figure 7 shows the distribution of the population in the region. The dense areas are in Lyon municipality (513 275 inhabitants) and some city suburbs with a mix of large residential buildings and some detached houses.

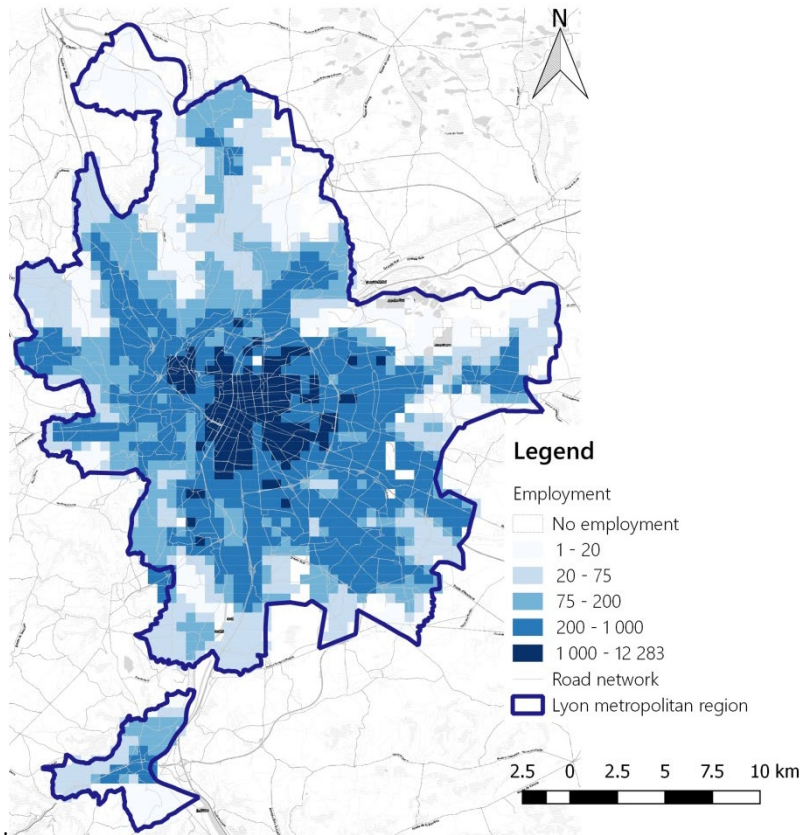
Figure 7. Population distribution (2011)



Source: French Census, 2015; ITF, map tiles by QGIS.

The majority of employment in the Lyon region is concentrated in the centre with some nearby external satellites (i.e. the area of La Duchère). Most of the employment areas of the city are quite well connected by public transport, which is used by a large share of commuters.

Figure 8. Employment distribution (2011)



Source: French Census, 2015; ITF, map tiles by QGIS.

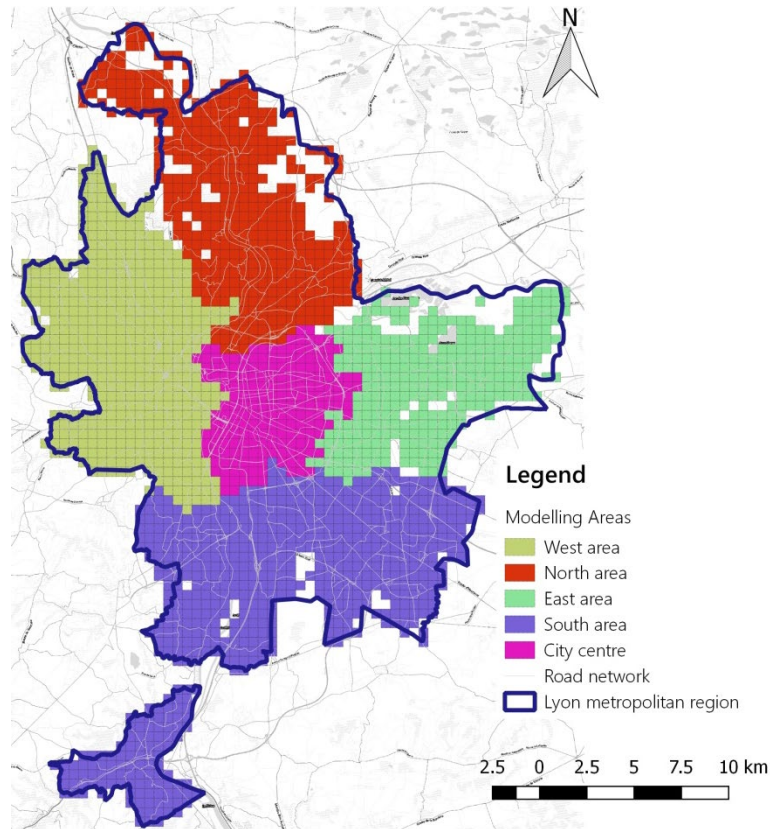
In order to increase the speed of the shared mobility simulation model, the study area was divided into seven functional sub-areas and 25 unidirectional corridors connecting the sub-areas. In these corridors, the probability is high that travellers will be able to share their rides, especially in the case of taxi-buses. The trip assignment optimisation was run in parallel for each of the corridors. Figure 9 shows the sub-areas and their conventional names.

Around 3.2 million trips took place within the LMR on an average workday in 2015. About 800 000 of them took place during the morning peak period from 07:00 to 10:00 (which amounts to 26% of the whole day), and 1 million during the afternoon peak from 16:00 to 19:00 (27% of the whole day). The majority of the trips are by private car (42%), closely followed by walking (38%) and public transport (18%), as shown in Table 2. The mode shares within Lyon proper are slightly different, with car share at 17% and non-motorised modes accounting for approximately 61% of the trips.

Over 150 000 people enter the Lyon city centre every morning and this number is expected to grow in the coming years. These commuting trips are mainly performed in private cars (34%) or public transport (39%), meaning that almost half of the people entering the city centre do so by public transport.

The road network plays a crucial role in the LMR's passenger transport, in particular for the periphery areas with lower public transport coverage. Several regional highways serve the LMR, including the A42, A43, A46, A532 and A450, and help distribute traffic within the metropolitan area. The A6 and A7 of the national network connect the city to other regions.

Figure 9. Lyon metropolitan region sub-areas used in the simulation model



Source: ITF, map tiles by QGIS.

Since the 1990s, transport planning authorities in the LMR have made efforts to encourage a shift from private cars to public transport and active modes like walking and cycling (Sytral, 2017). The plans were ambitious and the Grand Lyon planning authority succeeded in placing Lyon alongside Amsterdam and Copenhagen as one of the European metropolises with the highest non-motorised modal share. The region intends to strengthen this intense use of non-motorised travel in the future and expand favourable modal shares from the city centre to other suburban areas (Grand Lyon, 2016).

Table 2. Mode share distribution in the Lyon metropolitan region, 2015 (%)

Walk	Bicycle	Bus	Rail	Car + PT	Car	LRT	Taxi	Metro
38.2	1.9	5.9	0.1	0.9	41.5	3.1	0.2	8.3

Source: computed by ITF based on the Lyon metropolitan region mobility survey (Sytral, 2014).

The region has been enlarging and improving its public transport infrastructure and services in the last decades, lengthening road segments, adding stations and presenting new transport alternatives to the large LRT network. In France, the size of Lyon's public transport network is second only to Paris and provides services to 1.7 million passengers every day (Sytral, 2017). The entire system is publicly managed by Sytral for Transports en Commun Lyonnais (TCL) and either operated by Sytral or concessioned to another operator.

The Lyon bus network is privately operated by Keolis Lyon. It includes over 140 lines of buses and nine lines of trolleybuses that serve Lyon and the greater Grand Lyon area. The network consists of regular lines, as well as special services. The main bus network of Lyon is structured around lines indexed from C1 to C26; complementary lines, indexed from 2 to 100; specific and special lines that operate in some neighbourhoods, for events or to provide school access; and four nocturnal lines (Pleine Lune) that operate from 01:00 to 04:00 from Thursday to Saturday during university periods. The system integrates four on-demand lines called ResaGO in less dense areas of the region. Additionally, an on-demand transport network for the visually or physically impaired, called Optibus, operates from 06:00 to 01:00 every day (except May 1st) and serves the Metropolitan region, the communes of eastern Lyon and seven other municipalities in the urban transport perimeter. The system is also operated by Keolis.

Lyon's rail services are integrated into the national and regional systems, but this mode is marginal for commuting trips (Sytral, 2014). The original LRT network in Lyon was developed in 1879 and was reconfigured and updated in 2001. Currently, the system is organised in six lines (five urban lines and the Rhôneexpress, a line linking the city to the airport). The system stretches over 66.3 km and services 111 stations. There are currently plans to expand the system to include a sixth urban line (6.7 km and 14 stations) (Sytral, 2017).

The railway-based network is also integrated by the Funiculars of Lyon (Funiculaires de Lyon), a network of five original funicular lines. Only the two routes of the original system on the Fourvière hill remain in operation. The rest of the network has been closed, converted to road vehicle use, or integrated within the Lyon metro system.

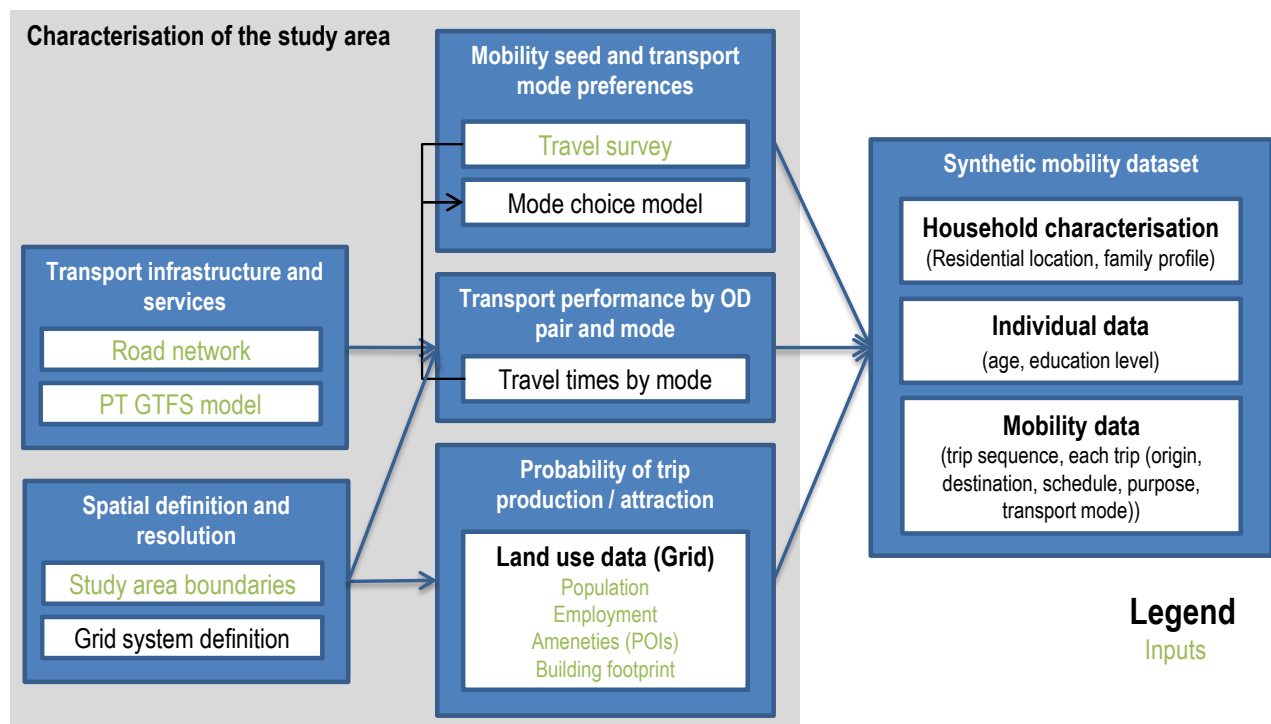
The Lyon metro serves 40 stations on four lines covering 32.1 kilometres. Plans are in place to consolidate the system and expand outside the Lyon municipality. The project is expected to last until 2030.

Modelling current travel demand

This section presents the major steps in the modelling of the current travel demand. They include preparation of the inputs, the mode choice model assumptions and the results estimated from the revealed preference data of the Household Travel Survey and their application to the generation of the synthetic population. The section also compares the results with the travel survey data. Figure 10 presents the connection between the different data sources and the final travel demand.

The first step to accurately assessing the impacts of the new shared modes is modelling, in the most detailed manner possible, the current mobility in the area. The model uses the revealed preference data from the Household Travel Survey to generate “synthetic mobility sets”, or a “synthetic population”. The synthetic population is represented by the socio-demographic characteristics of survey respondents, their household composition and their travel patterns that were then expanded to the total population. The modes used for the trips are defined based on the probabilities derived from an estimated mode choice model. These sets reproduce the entire personal mobility for an average workday in the region.

Figure 10. Procedures to model travel demand (current and future)



Notes: PT- public transport; OD – origin-destination; SM – shared mobility.

Source: ITF (2017a).

Model inputs

The following steps were taken to prepare the inputs for the mode choice model and to generate the synthetic population:

- dividing the area and assigning the travel survey, census and land-use data to the spatial units
- defining the travel survey respondents to represent the population and the travel modes to be included in the model
- defining available travel modes for each respondent; calculating the attributes of each available mode (travel time, travel cost, etc.), and computing the shortest path for each mode based on the total travel time.

To accommodate the spatial distribution of the trips in the model, the study area was divided using a variable grid size specification. The region's spatial resolution was calculated at two levels, as identified in Figure 11: the Lyon municipality and the rest of the LMR. The lowest grid-cell resolution is 500 m × 500 m and covers the LMR with 2 045 cells. The highest resolution of 200 m × 200 m is applied only to the Lyon municipality. Lyon municipality is covered with 2 386 of those cells.

The grids are built for a variety of modelling purposes. This grid system was used to link the residential data, the synthetic population's trip origins and destinations and the generation of travel alternatives. The 200 m × 200 m grid cells were used to better pinpoint trip origins and destinations within Lyon centre in the generation and attraction model of the synthetic population.

Data from the 2014 regional travel survey *L'Enquête Déplacements de l'Aire Métropolitaine Lyonnaise* (Sytral, 2014) for the Lyon metropolitan region were used to model the current mobility situation in the LMR. Some responses were excluded from the data for the mode choice model calibration so not to bias the model results. Among those were:

- Respondents younger than 18 and older than 65, who were assumed not to be decision makers for the mode choice. These respondents were included in the synthetic population but not in the choice model calibration since their travel patterns and mode choices depend on other members of the same household.
- Car passengers were excluded from the mode choice model as they are not faced with the same cost trade-offs. These respondents were preserved in the synthetic population trips. People who did not choose driving a car for the trips reported in the survey and/or had missing information about their driving license were also excluded.
- Respondents residing outside of the study area were excluded from both the synthetic population and the choice model input data.
- Trips which started and/or ended outside of the study area were excluded from both the synthetic population and the choice model input data.
- Trips where the reported mode choice violated the choice availability constraints presented below were also excluded.

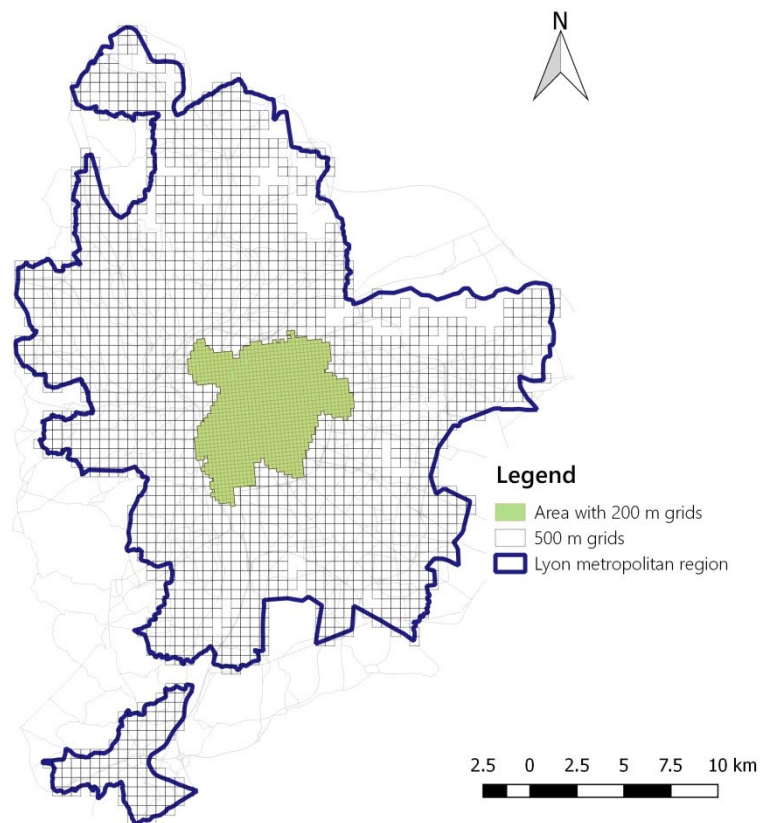
After the exclusion, 36 971 responses of the initial 37 125 for the whole LMR were kept and used in the mode choice model calibration.

The list of transport modes considered for the representation of current mobility includes active modes such as walking and cycling, private cars, taxis and public transport modes (bus, metro, rail and LRT).

Multimodal trips were aggregated into a single trip using a rule-based definition of main mode depending on the constituting trip legs in the following way:

- walking (if all the trip segments were conducted on foot)
- cycling (if all the trip segments were conducted cycling)
- private car (car, motorcycle driver or passenger, if there were no public transport trip segments)
- rail (if a private car is not used for part of the trip and train is the longest motorised segment)
- bus/coach (if a private car is not used for part of the trip and bus is the longest motorised segment)
- car + public transport (PT) (if both private car and PT heavy modes (rail) were used for the trip)
- LRT (if a private car is not used for part of the trip and LRT is the longest motorised segment)
- taxi (if a taxi was the only mode used or if the distance by taxi was longer in a taxi/car combination)
- metro (if a private car is not used for part of the trip and metro is the longest motorised segment).

Figure 11. Zones of different spatial resolution in the study area



Trips containing legs by plane and modes other than those established for the study, marked as “other”, were excluded. External sources, such as through traffic and visitors, were not accounted for in the model demand. Walking to and from a public transport stop represents “access” and “egress” respectively. Private cars are also an option for access, and the return trip is assumed to be symmetric.

The General Transit Feed Specification (GTFS) files for the study area were the main inputs for defining the mode choice sets (that is, the available modes), and the calculation of the modes attributes. For each trip the mode choice set was formed based on the following rules:

- walking is available if the distance between the origin and the destination is not more than three kilometres
- cycling is available for distances not more than six kilometres
- taxi is available for distances above 0.5 km
- the private car mode is not available for those who do not have a driving license
- the PT modes are available if a route was found such that the person does not have to walk more than 1 000 metres to the first PT stop, more than 1 000 m from the last PT stop and more than 250 m between the transfer stops
- car + PT is only available if the person has a driving license and for trips which meet the following criteria: the PT mode is rail or metro; the PT distance is not shorter than 1.5 km; the PT part of the trip is without transfers; the walking distance from the PT stop to the destination is less than one kilometre.

The shares of respondents for which certain modes are available are presented in Table 3.

Table 3. Availability of modes (% of respondents)

Walk	Bicycle	Bus	Rail	Car + PT	Car	LRT	Taxi	Metro
54.4	72.3	56.6	7.4	23.0	71.8	25.4	74.9	56.8

Based on the GTFS data, the origin and destination of the trip of each respondent and the availability of the shortest path (in terms of total travel time) were calculated for each mode. This allowed calculation of the mode attributes for each trip.

For trips using a PT mode, characteristics such as total travel time, in-vehicle travel time, total access and egress time, total travel cost (prices in 2014) and number of transfers were calculated for the totality of the trip, from origin to destination. Walking and waiting time were penalised based on data from Balcombe et al. (2004). Each transfer was heavily penalised.

For car travel, the shortest paths measured in travel time were calculated between all of the cells in the grid. The network speeds used for this calculation resulted from an average congestion level of the network of 50% (resulting from volume divided by hourly capacity for each link). The road network contains information on each link and is the basis for these calculations. The road network has been validated, ensuring that all the nodes are connected.

Mode choice model results based on revealed preference data

A multinomial logit discrete mode choice model was calibrated based on the data described above. The model allows the identification of the drivers of the mode choice, including trip attributes and socio-demographic characteristics of individuals that condition their decisions. The calibrated utility functions produce the probability of choosing each mode for each individual. Table 4 presents the model specification and calibration results. The variables include a common model coefficient for in-vehicle travel

time and different coefficients for the same variable in other modes. The model fit is high (rho-squared of 0.58) resulting from the significantly skewed mode selection towards car and walking, which provides a relevant role to the alternative specific constant (ASC).

Table 4. Estimated model parameters

Variable	Walk	Bicycle	Bus	Rail	Car + PT	Car	LRT	Taxi	Metro
Alternative specific constant	6.6700**	-2.2700**	3.8400**	1.2700**	4.3900**	5.1500**	3.8100**	0.0000	3.7700**
Travel cost (EUR)	n/a	n/a	-0.1810**	-0.1810**	-0.1810**	-0.1610**	-0.1810**	-0.1610**	-0.1810**
In-vehicle time (min)	-0.0885**	-0.0844**	-0.0308**	-0.0308**	-0.0308**	-0.0370**	-0.0308**	-0.0370**	-0.0370**
Access time (min)	n/a	n/a	-0.0234**	-0.0234**	-0.0234**	n/a	-0.0234**	n/a	-0.0234**
Waiting time (min)	n/a	n/a	-0.0613**	-0.0613**	-0.0613**	n/a	-0.0613**	n/a	-0.0613**
Number of transfers	n/a	n/a	-0.2430**	-0.2430**	-0.2430**	n/a	-0.2430**	n/a	-0.2430**

Note: * significant at the 95% level; ** significant at the 90% level.

The model calibration results give a value of time for public transport around EUR 10.20 and EUR 13.79 for private cars. These values are aligned with recent studies performed for France reporting a value of time of EUR 10.00 for commuting in 2010 averagely for the whole country and EUR 12.90 for the Île-de-France (Paris metropolitan) region (France Stratégie, 2014). Public transport transfers incur a connection penalty equivalent to 7.89 minutes' on-board time plus a perceived waiting time twice as penalising as the in-vehicle travel time. Public transport users value the access/egress time 24% less than the in-vehicle time.

Table 5. Mode share comparison with calibration data (subset of the Household Travel Survey, 2014)

Model	Walk	Bicycle	Bus	Rail	Car + PT	Car	LRT	Taxi	Metro
Estimated mode choice (passengers)	15 918	711	2 620	48	440	16 869	1 293	36	3 715
(%)	38.22	1.71	6.29	0.12	1.06	40.5	3.1	0.09	8.92
Household Travel survey choice (pax)	16 146	750	2 577	33	409	16 715	1 311	57	3 652
(%)	38.77	1.8	6.19	0.08	0.98	40.13	3.15	0.14	8.77
Estimated mode choice (pkm)	11 380	2 265	15 483	617	3 567	120 646	7 452	489	20 879
(%)	6.23	1.24	8.47	0.34	1.95	66.01	4.08	0.27	11.42
Household Travel survey choice (pkm)	20 087	2 964	11 990	396	4 415	110 612	7 354	484	24 475
(%)	10.99	1.62	6.56	0.22	2.42	60.52	4.02	0.26	13.39

The model results were validated by comparing the estimated mode choice options with the input survey data used to calibrate the model. The results are summarised in Table 5, which presents the number of respondents choosing each alternative and the corresponding mode shares in percentages.

Results show that model estimates align well with available data in terms of mode shares. The model, thus, reproduces the current mode choice behaviour with a high level of accuracy, even for modes with low mode shares. The model slightly overestimates bus usage and underestimates walking and modal mode shares in pkms. It should be noted that the numbers do not include trips by car passengers and other records excluded from the survey for the model calibration.

Synthetic population generation

The synthetic population model generates households with the following information: the household size and the characteristics of its members, their activity and the mobility to reach the activity location. The model takes into account the connections among household members and private vehicle ownership. The model relies on:

- Census data (spatially distributed population). The census data were available for census tracts. The census tract data were intersected with the grid, meaning that the corresponding values of population were computed for each grid cell based on proportions of its area belonging to census tracts.
- Travel survey with mobility patterns depending on the socio-demographic characteristics and the mode choice model calibrated based on these data. The mobility patterns include the trip purpose, departure and arrival times, if the trip is home-based or not, and the expansion factor of each individual survey. The mode choice model contains the coefficients of the utility functions of each mode, which are used to compute the probability of choosing each mode.
- Land-use data, based on the location of enterprise, establishments and amenities (grouped in nine types) in each grid cell of the study area for different types of activities (grouped in 38 categories based on the activities reported in the travel survey). The enterprises and establishments were collected from the Sirene database, while other amenities were extracted from the OpenStreetMap database. The groups of amenities include the following: offices, restaurants and bars, commerce and stores, hotels, shopping centres, hospitals, education centres, dwellings, recreational. The activities are: trips from work to a main job, from work to another job, from work to employers, business, education, shopping, social welfare, personal business/services, medical/dental, social visits/entertainment, recreational, accompany someone else, overnight lodgings, returning home, other. The activities were aggregated into nine groups to be linked with the amenities.

Each individual from the travel survey is replicated in accordance to the expansion coefficient. For each, the agent-based model generates the structural activity representing habitual trips (work, school, etc.), and discretionary trips (shopping, recreational activities, social visits, etc.) with the time of day attributed to each kind of activity. The activity pattern of each individual from the synthetic population remains the same as the “seed” individual from the survey. The trips’ attributes, including origin and destination, start time, duration and mode, are based on the original seed but include a stochastic component.

The synthetic population model generates 876 549 mobile persons (1 339 534 inhabitants) that reside inside the modelled area with 3 119 307 trips for an average weekday in 2012. This leads to a trip production rate of 2.33 trips per inhabitant. This value is an average and comparable with medium- to high-income cities like Vienna (2.66), Turin (2.44), Singapore (2.45) or Vancouver (2.52) in 2012 (UITP, 2015). The synthetic population does not include non-residents or visitors to the study area. This component, while small (for example, 4% of mobile persons in Greater London are visitors and 8% are

non-resident commuters (TfL, 2014); for a smaller city like Lyon, which is neither a capital nor a major touristic attraction, this percentage should be considerably less), can lead to an underestimation of congestion in the simulation. However, this bias does not affect the comparison since the baseline model and the shared mobility scenarios exclude this component.

The simulated population matches the mobility survey responses well. Table 6 shows how the probabilistic trip mode of a synthetic person matches the corresponding trip mode of the seed person (a person from the survey based on which a synthetic person was generated using the expansion factor). The diagonal of the table presents the correct predictions, which are quite high for the most used modes (walking and private car) and are lower for the other modes. Since the final mode shares and the pkm of the synthetic population and the travel survey are very similar, the disparities do not create a problem but reflect the stochastic nature of the synthetic population model. The aggregated results in Table 7 are in persons, as distinct from the pkm mode shares presented in Table 5.

Table 6. Synthetic population mode shares (vertical) versus seed mode shares (horizontal) (%)

Modes	Walk	Bicycle	Bus	Rail	Car + PT	Car	LRT	Taxi	Metro
Walk	71.10	1.11	2.08	0.01	0.17	18.29	0.82	0.03	6.39
Bicycle	22.80	12.96	6.11	0.01	1.75	35.88	5.94	0.01	14.54
Bus	26.06	3.73	26.13	0.30	2.23	23.68	5.85	0.38	11.63
Rail	1.69	2.81	10.68	2.57	6.38	64.39	1.32	2.09	8.07
Car + PT	1.15	0.12	1.60	0.37	2.17	87.90	1.60	0.18	4.91
Car	19.05	1.83	7.07	0.20	1.49	62.77	2.35	0.10	5.14
LRT	13.01	0.96	7.91	0.03	1.20	32.98	24.14	0.01	19.76
Taxi	6.38	5.60	13.04	1.72	2.67	40.99	3.26	6.21	20.13
Metro	6.35	0.39	7.19	0.04	1.75	46.79	6.75	0.01	30.73
Mode share	38.22	1.71	6.29	0.12	1.06	40.50	3.10	0.09	8.92

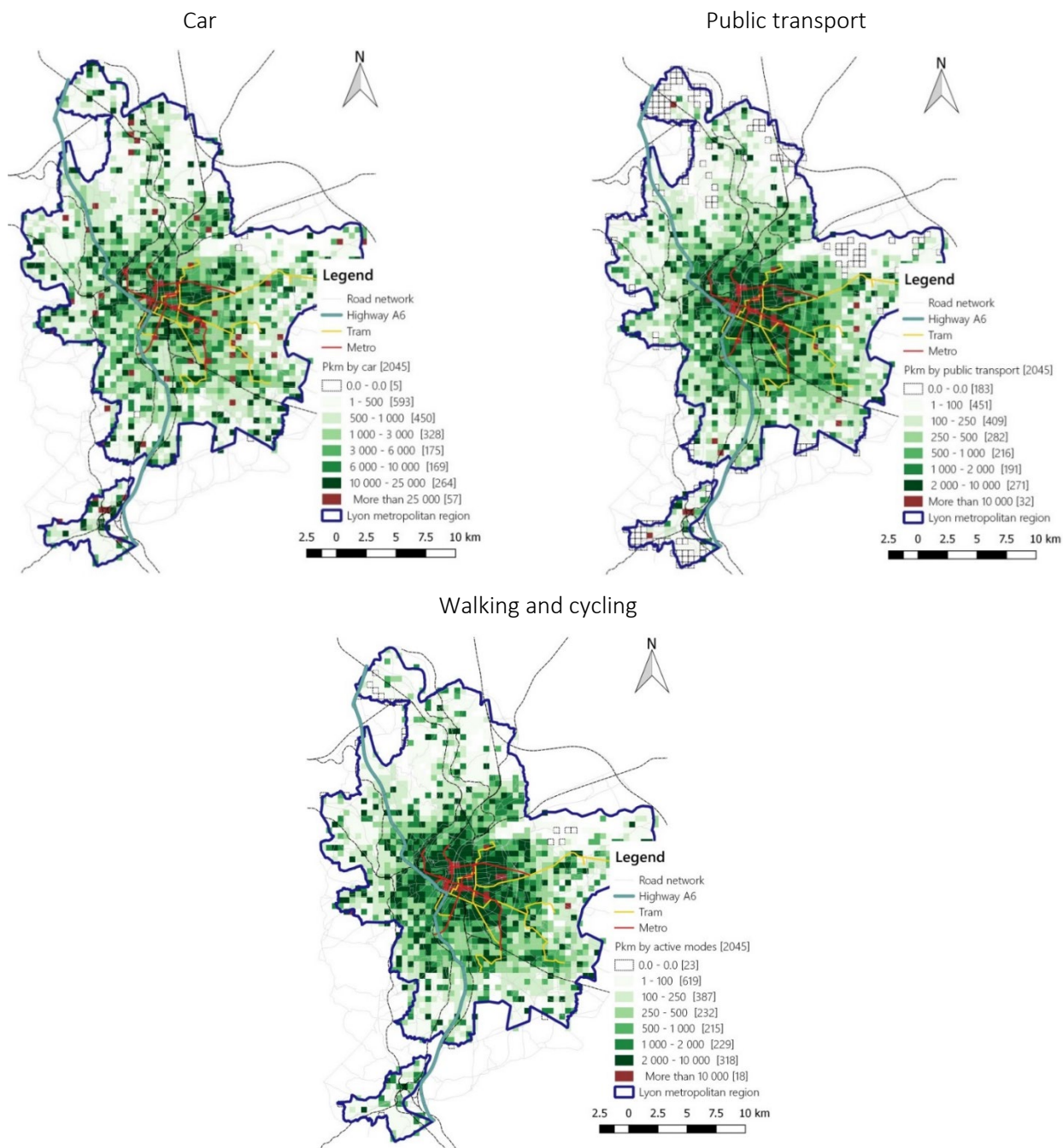
Table 7 presents the characteristics of an average trip generated for the synthetic population. As the table shows, residents of the study area use public transport mostly if no transfers are required and if the stops are within, on average, six minutes' walking distance from the origin or the destination. The frequency provided by the existing public transport results in low waiting times, with low-frequency services being used only for very long-distance travel. The total access and egress average time is high. That leads to total travel time by public transport being three times the total travel time of cars, even with the lower average travel distance associated with a trip by PT.

Table 7. Average characteristics of a trip (within the study area)

Travel mode	Total travel time (min)	Travel distance (km)	Number of transfers	Access + egress time (min)	Waiting time (min)
Public transport	46.62	5.85	0.67	25.99	7.90
Private car	31.41	11.84	n/a	n/a	n/a

The synthetic population enables the analysis of the current mobility distribution in space and time. Figure 12 displays the pkm by car, public transport and soft modes of trips originating in each grid cell per square kilometre. The scale is divided into classes with approximately the same number of observations in each class (quantiles). As the three figures show, the central part of the LMR generates most of the pkm, while the areas outside of the central part generate much more pkm by car than by other modes.

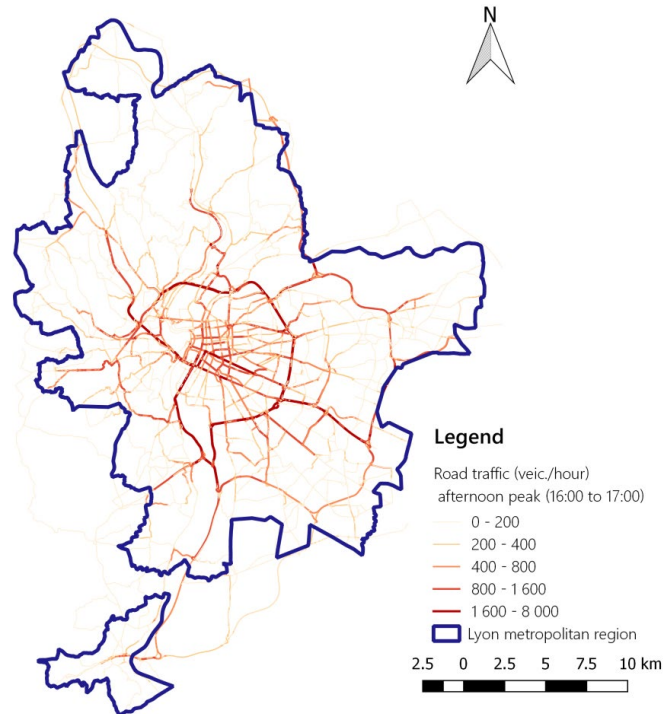
Figure 12. Daily passenger-kilometres in the LMR under the current mobility practice by car, public transport, walking and cycling and by grid cell of trip origin



Source: ITF, map tiles by QGIS.

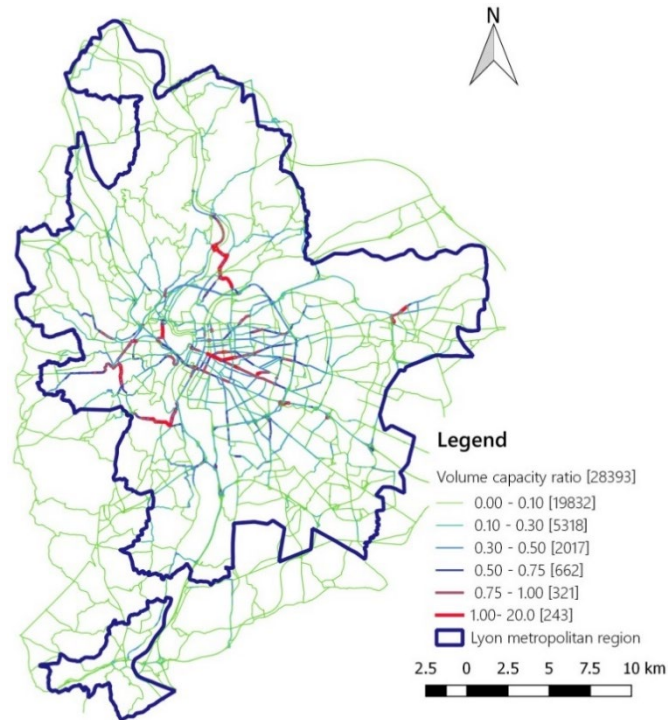
Assigning the synthetic population trips to cars shows that congestion is quite high along some of the road network links in the study area. Figure 13 shows the traffic flow in the evening peak and Figure 14 the congestion for each road network link in the evening peak. The congestion is represented by the volume to capacity ratio. The congestion level for most of the links is quite low (the volume to capacity ratio is below 0.3). It is substantial, however, for the main roads (volume to capacity ratio above 0.75).

Figure 13. Traffic flow in the road network (evening peak), current mobility



Source: ITF, map tiles by QGIS.

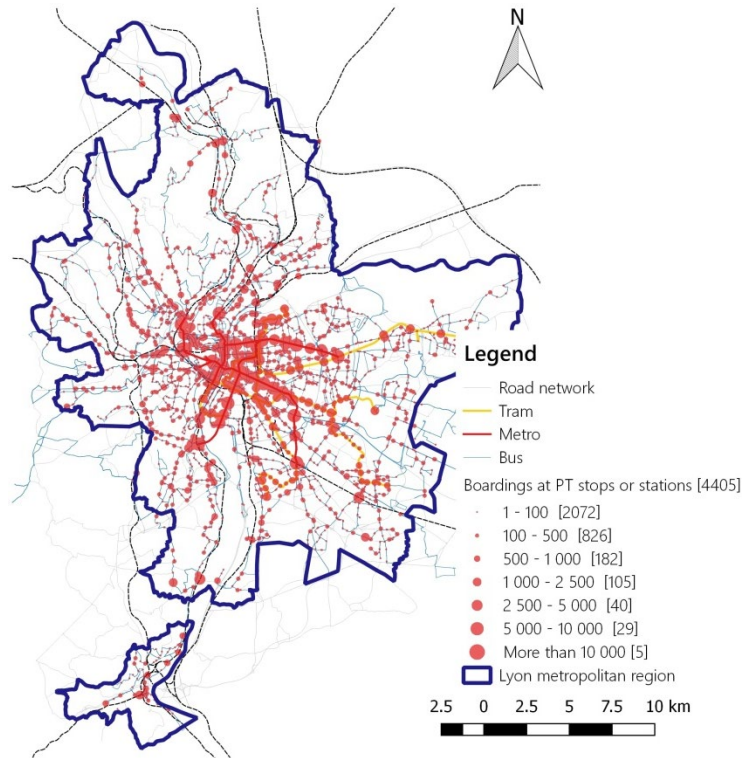
Figure 14. Congestion for each road network link (evening peak)



Source: ITF, map tiles by QGIS.

Observations based on the synthetic population show high use of public transport or non-motorised transport in the city centre. The focus of private car use is outside the city, where public transport service is less developed. At the same time, the capacity of many main roads towards the city centre is not sufficient to provide congestion-free movement for motorised vehicles. Therefore, the possibility of diverting users from cars to more sustainable modes with higher occupancy rates is of special concern in the study area.

Figure 15. Ridership by number of boardings at each station for the baseline scenario



Source: ITF, map tiles by QGIS.

The model estimated current public transport boarding patterns. Figure 15 illustrates the trends. The results show high metro use Lyon’s city centre, the interaction with the LRT network and that some regional rail lines also feed traffic into the city. Bus boardings are more concentrated at locations where heavy public transport (LRT, metro and rail) is absent or at stations in Lyon’s city centre providing access to suburban areas.

Potential users of shared mobility

The successful introduction of shared mobility requires an understanding of the potential users' mobility preferences. The ITF organised a stated preference survey (SP) to investigate these preferences. The survey helped to identify and quantify the most important attributes of the new modes as well as the social-demographic characteristics of the users influencing mode choice. The analysis of the SP survey results used a combination of qualitative and quantitative methods to take user preferences into account, by means of the utility functions, in mode choice in the simulation model. The findings of the survey also helped to identify potential early adopters of shared mobility and provided insights for a design of the new shared modes more tailored to the potential users' needs.

Stated preference survey

An online survey aimed at collecting data for quantitative (by means of discrete mode choice model) and qualitative analysis was disseminated among citizens of Lyon with the help of the Urban Development and Living Environment Delegation of the Lyon metropolitan region. The survey was adapted to the local terminology and context of the LMR, including available PT modes, costs of the alternatives, etc. In total, 63 individuals responded to the survey. The survey contained four sections:

- **Respondents' profile**, containing questions about socio-demographic characteristics of the respondents and their residential location, including proximity to the city centre. These questions enabled the assessment of the representativeness of the sample. It also allowed the inclusion of the corresponding variables into the utility functions of the choice model estimated from the survey. Additionally, the section contained questions regarding the level of familiarity with relevant technologies. Answers to these questions revealed how willing the respondents were to use the proposed services if they required the use of smartphones and applications.
- **Stated preference scenarios (choice games)** in which respondents chose from one of the four available modes to make the same trip. This provided the main input for the discrete mode choice model. The modes were combined into four groups: private car, PT (bus, rail, metro or tramway), non-motorised alternatives (walking or cycling) and shared modes (shared taxi, taxi-bus, or carpooling). Each respondent faced nine choice games. In the first five, the respondents had to choose four options, one from each mode group. The shared mode in the first group of the choice games was unspecified, i.e., no distinction was made between shared taxis and taxi-buses. In the other four choice games, the respondents chose between a shared taxi, a taxi-bus, carpooling as a passenger, and carpooling as a driver, given their attributes for the same trip. Each choice game presented relevant modes' attributes including access time (shared modes, PT), on-board time (all motorised modes), cost (all motorised modes), detour time (shared modes), the number of passengers sharing the vehicle (shared modes), walking/cycling time for non-motorised modes, the number of transfers and waiting time for PT.

The combinations of the modes' attributes for each choice game and for each block were generated using an experimental efficient design in order to maximise the precision of estimated choice-model parameters for a given number of choice questions. For that, 72 scenarios were split

into eight blocks, so that each respondent would face one block. Annex A presents an example survey question as the respondents would see it on the screen.

- **Mobility background**, revealing the respondents' daily trip patterns, including the main activities, frequencies, distances and typical modes used for each trip purpose. The respondents also had to categorise themselves as one of the following: regular car user, regular bus user, regular rail user or regular non-motorised traveller. This enabled the following survey section to adjust questions to each respondent based on his or her mode preferences.
- **Attitudes towards shared mobility attributes**, including main features of the proposed shared mobility services compared with the respondents' current most-often used mode and acceptable values of the shared modes attributes. For most of the attributes, the respondents were asked to rank the total acceptable value in a suggested range in terms of cost, waiting time, number of passengers on board, etc. For other attributes, respondents were asked to rank the degree of importance from "not relevant" to "highly important" for attributes such as the ability to use the shared modes as feeder services to rail, for example. Additionally, this section contained questions regarding the household's car ownership, parking preferences and willingness to sell some of their personal vehicles in the presence of shared modes on a large scale. The section described the design of the shared modes to ensure the level of service accepted by a majority of potential users.

The following sections present the main findings obtained based on the responses to each survey section. These include descriptive statistics and the results of the estimated mode choice model.

Respondents' profiles and mobility background

The survey contains questions on socio-demographic characteristics of the respondents, their familiarity with the related technologies, and their current mobility patterns. Detailed results are available in Annex B.

The distribution of the respondents across the area is balanced: nearly half of the respondents live within ten kilometres of the city centre. Younger people are underrepresented in the survey, with respondents under 25 years old missing from the sample. The biggest share of the respondents is from the 46- to 55-year-old age group. This might make the sample biased towards more traditional modes, since the previous ITF studies on shared mobility (ITF, 2017a; 2017b; 2018) showed that younger people will likely be earlier adopters of the shared modes. Most of the respondents are full-time employees. The share of respondents who neither work nor study is around 5%.

More than 90% of respondents own and use a smartphone, and around 45% use a tablet. More than half of the respondents actively use their smartphones, which includes accessing real-time information about weather, news, etc. More than one-third use smartphone apps to request transport services.

The average number of weekly trips is 13.7 per person. Most trips (36%) are commuting to or from work or a place of study, with an average trip duration of 47 minutes, which is the longest average travel time among trips of different types. The other most common type of trips is travel to drop off or pick up children at school or childcare (17%), with an average duration of 20 minutes. Daily shopping trips, social activities (e.g. visiting friends or family) and leisure activities (e.g. sport) are equally common (totalling 12%).

Around one-third of the respondents defined themselves as regular car users and one-third as cyclists. They are followed by railway users with a 15% share. Younger respondents (under 36 years old) tend to use soft modes more often. For all trip types other than leisure, more than half of the respondents use private cars as a driver; for leisure trips, this share is more than one-third.

Attitudes towards shared mobility attributes

The survey included a section with questions regarding the attitudes towards the attributes of the shared modes compared to the current regularly-used mode. The section contained questions regarding fare, access time, time lost during detours to pick up and drop off other passengers, transfers, the possibility of using shared mobility modes as feeder services to rail and ferry stations, etc. Annex C presents the answers split by the mode user type (car or PT).

First, the respondents answered a question about the price they were willing to pay for the shared modes. Instead of the absolute value, the question suggested comparing the maximum acceptable cost of a ticket for a shared mode with the current cost per trip by car or by a PT mode.

For car users, a benchmark figure of EUR 20 total cost per average trip was calculated using not only out-of-pocket expenses for fuel but also the purchase price of the car, road tax, insurance and maintenance. Car users' willingness to pay for a trip by a shared mobility mode was measured on a scale of 1 to 10: 1 being a refusal to use the shared modes; 5, a willingness to pay half of the current cost of shared mobility modes, and 10, a willingness to pay the current value. One-quarter of the car users surveyed stated that they were not willing to use the shared modes at all. Around 20% of the car users were only willing to pay half the current cost, and only 5% were willing to pay the current cost.

Bus and rail users also had to compare the cost they would be willing to pay for the shared modes with the current PT fare. As above, willingness to pay was measured on a 1-10 scale where 1 represents a total lack of willingness to pay for shared modes; 5, a willingness to pay the equivalent of the current price; and 10, a willingness to pay twice the price. Most of the PT users are willing to pay a fair comparable price to the current PT ticket price.

The respondents were also asked how long they would accept to walk to a stop of a shared mobility mode. Around 10% of car users and almost all public transport users were willing to walk ten minutes or more. Most car users would accept walking five minutes (a distance of approximately 400 metres).

Half of the PT users and around 40% of car users stated that they would be willing to lose ten minutes in total travel time due to detours for passenger pick-up and drop-off. Around 20% of all respondents would accept to lose ten minutes or more. None of the respondents would be unwilling to accept any detours.

All the respondents answered a question regarding the relevance of shared modes as feeder services to or from rail stations subject to the condition that the rail trip is direct. One-third of car users and half of the PT users stated that the feeder service would be highly relevant to them. This can be explained by the fact that around half of the respondents lived more than ten kilometres from Lyon's city centre. Rail can provide a fast means of travel for long-distance trips in the LMR, especially where access to the railway station is quick and easy. Around 15% of car users and 25% of PT users stated that the feeder services would not be relevant to them at all. These are likely to be the users who were either well served by the current PT in terms of access time and the absence of transfers, or preferred to keep using their private cars instead of the shared modes.

Additional questions targeted particular groups of respondents based on the travel mode they used most often. Regular car users responded to a question on the number of passengers with whom they would be willing to share a trip by a shared mode. None of the car users stated that they would not like to share with anyone. One-third said they would be willing to share a vehicle with 10-15 other passengers.

The final question asked about the household's car ownership, parking preferences and willingness to sell some of the household's cars if the shared services became available on a large scale. More than half of the respondents' households had a car and 27% had more than one car. More than 85% of the respondents

who owned a car parked it in a private garage. Of the respondents who owned more than one car, 40% stated they would be willing to sell one.

Stated preference choice experiments

At the core of the survey was a set of stated preference questions in the form of nine choice games. The results were used to determine the respondents' perceptions of shared mobility and their potential impact on mode choice. The modes available in the scenarios were walking, cycling, bus, rail, tram, metro, car and shared mobility modes. Each respondent answered nine choice games: five games with choices among three existing modes (a non-motorised mode, a PT mode, and car) and a generic shared mode; and four games with choices between shared taxi, taxi-bus and carpooling. Annex A shows an example of a typical choice game.

The stated preference data obtained from the survey were used for the calibration of a multinomial logit discrete choice model. Table 8 presents the model coefficients and values based on the survey, along with goodness of fit measures. For the estimation, the alternative-specific constant of car was normalised to zero. The coefficients that were found to be significantly different from zero (at the confidence level of 90%) were kept in the final model. A few coefficients that did not meet that criterion, but usually strongly influence the mode choice, were also kept. These included, for instance, alternative-specific constants and coefficients related to the modes' levels of service, such as travel time and cost. The rest of the coefficients were set at zero.

Different specifications were tested, including nested logit. The introduction of nests did not improve the model fit and the calibrated nests' scale parameters were not significantly different from one. The goodness of fit expressed by rho-squared was quite low, which was likely due to a large number of modes included in each choice game and highly diverse answers of the respondents.

The value of time (VOT) for car users and PT users is comparable to those reported in other studies for Europe (e.g., Wardman et al., 2012). The VOT of the shared mode users is between the VOT of car and PT users, which can be expected for modes that combine features of a conventional taxi and a bus.

The estimated alternative-specific constants reveal that there are underlying preferences for PT and shared modes. This indicates that there are net unobserved benefits for rail and shared modes compared to private car use.

The estimated coefficients of the model reveal that the preferences of regular car users for the shared modes are higher than those of PT users, and that taxi-bus options are the least favoured among shared modes. Carpooling is also positively perceived, but mainly as a passenger. Riding alone in a shared taxi has a positive coefficient, indicating that the respondents have a high willingness to pay for being alone in a vehicle (EUR 4.56 for a trip to be alone in a vehicle). This implies a possible cultural characteristic where people privilege privacy over cost and are willing to pay to avoid conversation with other passengers.

Table 8. Model coefficients and values based on stated preference results

Parameter	Estimated value
Alternative specific constant, bus	0
Alternative specific constant, car	0
Alternative specific constant, cycle	0
Alternative specific constant, metro	0
Alternative specific constant, rail	1.390*
Alternative specific constant, shared mobility	1.770*
Alternative specific constant, tram	0
Alternative specific constant, walking	0
Alternative specific constant, carpool driver	0.514
Alternative specific constant, carpool passenger	1.21*
Shared mode: taxi-bus, for car users	-1.56
Access time, generic (PT and shared mobility)	-0.044*
Being a car user, shared mobility	0.53
Travel cost, car	-0.236*
Travel cost, PT	-0.292*
Travel cost, shared mobility	-0.137*
Being female, shared mobility	0.178*
Lost time, shared mobility	-0.089*
Number of transfers, PT	-0.323
Number of passengers, shared taxi	0.0823*
Number of passengers, taxi-bus	0.273**
Riding alone, shared taxi	0.63**
Travel time, car	-0.073**
Travel time, non-motorised modes	-0.122*
Travel time, PT	-0.042*
Travel time, shared mobility	-0.028*
Waiting time, PT	-0.046*
Living far from the city centre, car	2.88**
Living close to the city centre, shared mobility	0
Living close to the city centre, PT	0
Being less than 25 years old, shared mobility	0.064*
Adjusted rho-squared	0.151
Number of observations	416
Value of time (EUR per hour), car	18.56
Value of time (EUR per hour), PT	8.61
Value of time (EUR per hour), shared mobility	12.31
Correctly predicted choices (full sample), %	58
Value of riding alone (EUR), shared taxi	1.59

Note: * significant at the 95% level; ** significant at the 90% level.

The estimated model coefficients show that the travel cost is the most important attribute for the mode choice of car users. In the case of PT, the most important coefficients are the number of transfers, followed by travel cost, waiting time, access time, and in-vehicle travel time, whereby the latter three are nearly equally important.

Analysis of the differences in mode choice preferences depending on socio-demographic characteristics showed that female and younger users (under 25 years old) favour the shared modes more than others. Location of residence is only important for the private car choice when respondents live more than ten kilometres from the city centre.

The results show that the benefits which shared mobility can bring to a city strongly depend on the number of car users who shift to the shared modes. As previous studies by the ITF have shown, the larger the shift the greater the improvements to mobility in terms of congestion, emissions and equity. The desired mode shift requires an acceptance of the new modes by car users, as buyers and as voters. The survey results show that the shared mobility modes are quite positively perceived by car-using participants and that some of them would be willing to substitute their car trips with trips by the shared mobility services and to reduce their private car ownership. The results from the survey clearly indicate the need for public awareness campaigns for citizens to clearly understand the role of shared mobility in urban transport. The acquaintance of users with the system attributes and their range is extremely important for a strong uptake of shared mobility, especially under the more sustainable configurations.

Setting the shared mobility scenarios

Survey results showed that travellers in the LMR would be interested in using shared mobility to bridge private and public transport modes. They also showed that new shared mobility modes could achieve a considerable ridership, even with no additional incentives from the authorities. However, policy makers, investors and users alike need to know the performance of shared modes under various transport system configurations, as it will strongly affect the success of the uptake and financial viability of the new transport system they help to create. The transport system configurations may vary depending on the presence and attributes of the new shared and the remaining “conventional” modes, on the restriction of car use in space and time, and on mode split of the users. This section presents scenarios with different transport system configurations and different degrees of market penetration of the new shared services. The scenarios are designed to test the performance of the LMR transport system in its evolution from the current situation to a fully adopted shared mobility solution.

Previous ITF studies on shared mobility (ITF, 2017c) showed that replacing car trips at marginal rates does not have a significant effect on CO₂ reduction. Therefore, the minimum car replacement rate considered in all the scenarios is 20%.

Table 9 shows the selected scenarios. Scenario 1 (Sc. 1) assumes that motorised modes are fully replaced by shared mobility in the LMR, and compares common indicators with those from similar ITF shared mobility studies in Auckland, Helsinki, Lisbon and Dublin (ITF 2017a, 2017b, 2017c and 2018).

Scenarios 2 and 3 assume a lesser degree of migration from private car use to shared alternatives, set at 20%. In scenario 2 (Sc. 2), bus operation is fully replaced by flexible shared services, whereas scenario 3 (Sc. 3) preserves the high-frequency bus lines in the region (headways less than or equal to five minutes).

Scenario 4 (Sc. 4) was developed specifically for the Lyon case study. It tested carpooling as a single shared mobility option along the city access corridors of West-City centre and South-City centre. If no pool was available (considering the needs of the symmetrical trip), customers continued using their present choice.

The last tested scenario, scenario 5 (Sc.5), included a low-emission zone (LEZ) with restrictions on car usage. The design of LEZ boundaries aimed to maximise the potential of park-and-ride in the study area.

Typically, the scenarios included three shared modes – shared taxi, taxi-buses and carpooling (as a driver or a passenger) – and the feeder services as described in the “Shared modes specification” section. Use of the existing PT modes and private car varied across the scenarios, with full or partial retention of certain modes and links. All scenarios relied on a set of common rules for mode choice: bike users continued to use a bike; those who walked kept walking for distances below three kilometres and otherwise shifted to one of the shared modes; conventional taxi mode was removed from the transport system, so its users shifted to the shared modes, as well. Rail and LRT modes were retained with their current characteristics. Each rail user continued to use rail if both origin and destination stations were within acceptable walking distance and no transfers were required. Otherwise, the user chose shared mobility either for a direct trip or as a feeder service to rail. The LRT mode was retained, but with limited feeder services provided by shared modes, as it assumed that most of the current LRT stations did not have the capacity to support the massive drop-off of passengers. Where an LRT station was within 200 metres of a rail station, the LRT station served as a drop-off and pick-up point for shared modes to provide feeder services for both LRT and rail.

The choice between feeder to rail and direct service by a shared mode was based on the computed choice probabilities and the rules for feeder services. Differential weights were assigned to walking (three times more) and the connecting taxi-bus time (1.5 times more) as compared to the time spent travelling onboard the train. The user was assigned to the feeder service if 1) the walking segment linking rail with the trip endpoint (origin or destination) was less or equal to ten minutes; (2) the rail leg had no transfers; or (3) the total distance on the feeder part of the trip (walking plus shared mobility) was shorter than the direct distance between the trip origin and destination. This ensured that feeder services did not result in long detours from the most efficient path. A feeder service was only allowed at one end of the trip so that the entire trip had no more than one transfer. If at least one of these conditions did not hold, the user was assigned to a direct service by a shared mode.

Table 9. Scenarios selected for tests

Scenario number	Bus	Car	Rail, LRT	Shared mobility modes
1	100% Replacement	100% of trips replaced	Keep	Shared taxi, taxi-bus and carpooling
2	100% Replacement	20% of trips replaced	Keep	Shared taxi, taxi-bus and carpooling
3	Keep trips where Bus with headway <5 min	20% of trips replaced	Keep	Shared taxi, taxi-bus and carpooling
4	Keep	100% of trips replaced that prefer carpooling. carpooling corridors	Keep	Carpooling
5	100% Replacement	Low Emissions Zone (LEZ) with all private car traffic constrained within LEZ, 20% of car users affected by LEZ restrictions use the shared modes from the origin	Keep	Shared taxi, taxi-bus and carpooling

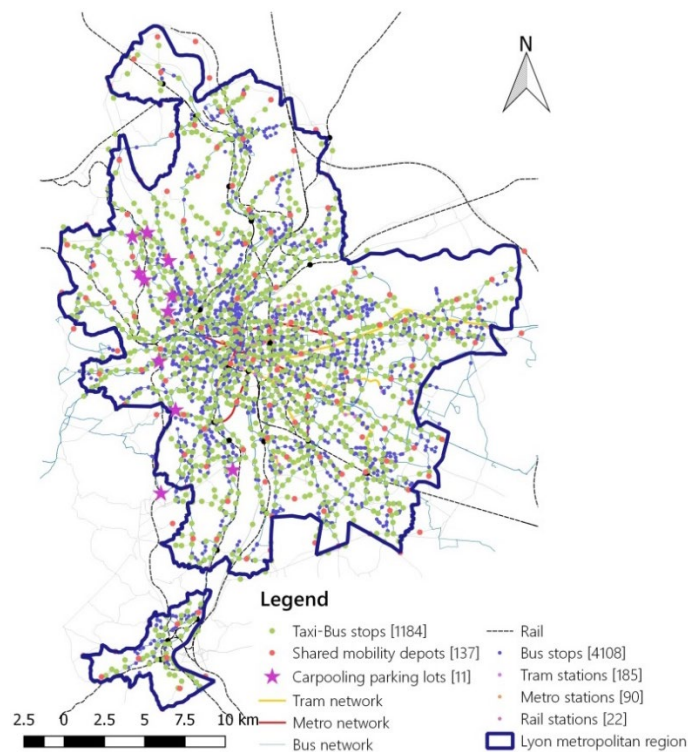
Car users shifted to shared modes according to the availability of alternatives in each scenario. The probabilities computed in the mode choice model (found in section “Stated preference choice experiments”) helped determine which car users would shift to the shared modes in partial adoption scenarios. The choice probabilities were based on the utilities of the competing modes computed for each individual and trip, depending on the person’s socio-demographic characteristics and the mode-specific attributes for the trip. Car trips were sorted in ascending order according to the ratio between the probability of choosing a shared mode to the probability of choosing a private car; earlier adopters are chosen from the top of this sorted list. The term “early” in this case does not imply a specific time component and refers to those users who have greater computed probabilities to shift to the new modes. The number of chosen early adopters was defined by the car replacement share of the scenario. The rest of the inhabitants continued using cars. The shared mobility study for the Lisbon metropolitan area (ITF, 2017c) showed that replacing car trips at marginal rates does not have a significant effect. Therefore, the minimum car replacement rate in all scenarios was 20%. This was also consistent with the focus group and stated preference survey findings, which suggested that a 20% replacement rate was a plausible scenario.

If a person chose a shared mode, the specific choice of taxi-bus, shared taxi or carpooling was based on the estimated choice probabilities and the “supply services availability” scenario setting. This setting matched the user’s desired travel data with available service options at the time of the request. If the

requested travel mode was not available, the user was transferred to a different, comparable mode, often upgraded at no cost.

Carpooling services followed a similar dispatch procedure: if no carpool met the user’s request data, the service was transferred to a taxi-bus for that trip. If there was no other shared mobility alternative, customers that preferred carpooling returned to their previous travel mode.

Figure 16. Road, public transport and potential shared mobility networks



Source: ITF, map tiles by QGIS.

Shared taxi fare was assumed to be equal to 75% of the current car cost but never less than EUR 3. Taxi-bus fare was assumed to be 50% of the current car cost but never less than EUR 1.50. The cost of a private car was calculated as EUR 10. This took into account the daily value for the purchase price of the car, insurance, road tax and maintenance divided by three trips per day, plus fuel cost per kilometre. Carpooling costs resulted from a cost split between the driver and the other riders, with the parking costs set at zero in the dedicated parking facilities outside the city where carpoolers met. The onboard travel time (which also included detour time) of a taxi-bus was constrained such that it never exceeded the time needed to travel along a Euclidian distance between the trip origin and destination at a speed of 15 km/h.

Whenever a shared taxi was empty and not dispatched to a new trip, it moved to the nearest depot for idle vehicles. Figure 16 presents the location of potential taxi-bus and shared taxi stops and depots. The locations were optimised to maximise coverage, subject to the following constraints: each node of the road network that belonged to the grid was within 400 m of the closest taxi-bus stop; every grid centroid was less than two kilometres from the closest depot; each node in the road network grid was no more than ten minutes from the closest depot, the maximum acceptable waiting time for a shared taxi (Table 1).

The shared mobility scenarios can be split into four groups: those with different specified degrees of bus and car trip replacement (Sc. 1-2); those which keep frequent bus trips (Sc. 3); those devoted to carpooling

option assessment (Sc. 4); and a scenario with restriction to car usage in a city area (LEZ with restricted access for private cars, Sc. 5). The scenarios' specific features for each group are presented below.

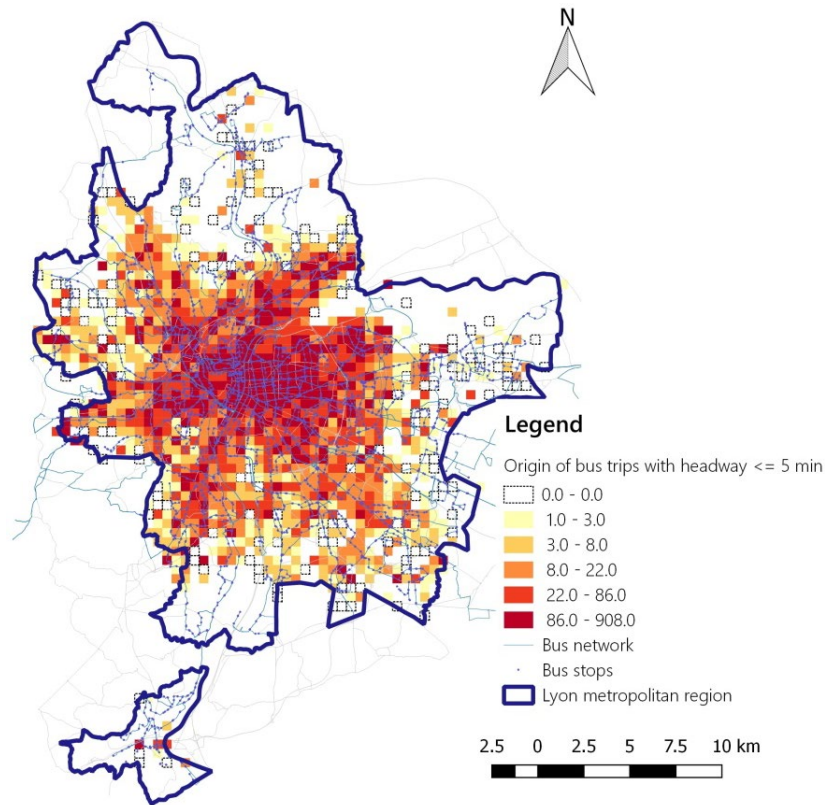
Scenarios with different degrees of replacement for bus and private car trips

The first group of the scenarios tested how different degrees of replacement of car trips, with and without a bus network, impacted the performance indicators of the transport system. The replacement rates for car trips were 100% (Sc. 1) or 20% (Sc. 2). Bus trips were either entirely replaced by other modes (Sc. 1, 2, 5), replaced partially, keeping just the highly frequented buses (Sc. 3) or were unchanged (Sc. 4). Metro and rail trips were kept if they did not require transfers. Otherwise, they were substituted either with direct trips by shared modes or with trips where a shared mode fed rail based on the rules described in the previous section. LRT trips were kept if they were not part of a trip chain containing trip legs by bus and if the sum of access time and waiting time of the trip did not exceed 30 minutes. LRT trips that did not meet these requirements were substituted with direct trips by shared modes or, in rare cases, by shared modes feeding the LRT, as described in the previous section.

Scenarios retaining frequent bus trips

Scenario 3 analysed how the retention of the “core” bus network alongside the introduction of shared modes would impact on the performance and efficiency of the transport system. This study considered the “core” bus network to be all bus services that operated with headway less or equal to five minutes. Figure 17 shows the origins of the preserved bus services. The bus trips with a frequency greater than five minutes were replaced with trips by the shared modes while the rest were kept. The results show a spatial pattern with greater intensity in the city centre and along some specific corridors and during the morning and afternoon peak for direct suburban services.

Figure 17. Origins of the kept bus trips and the core bus network



Source: ITF, map tiles by QGIS.

Rail and LRT trips were kept or substituted with shared modes following the same rules as in the first group of scenarios. The choice of the trips to be replaced depended on the mode choice probabilities, as described in the introductory part of this section.

Carpooling corridors

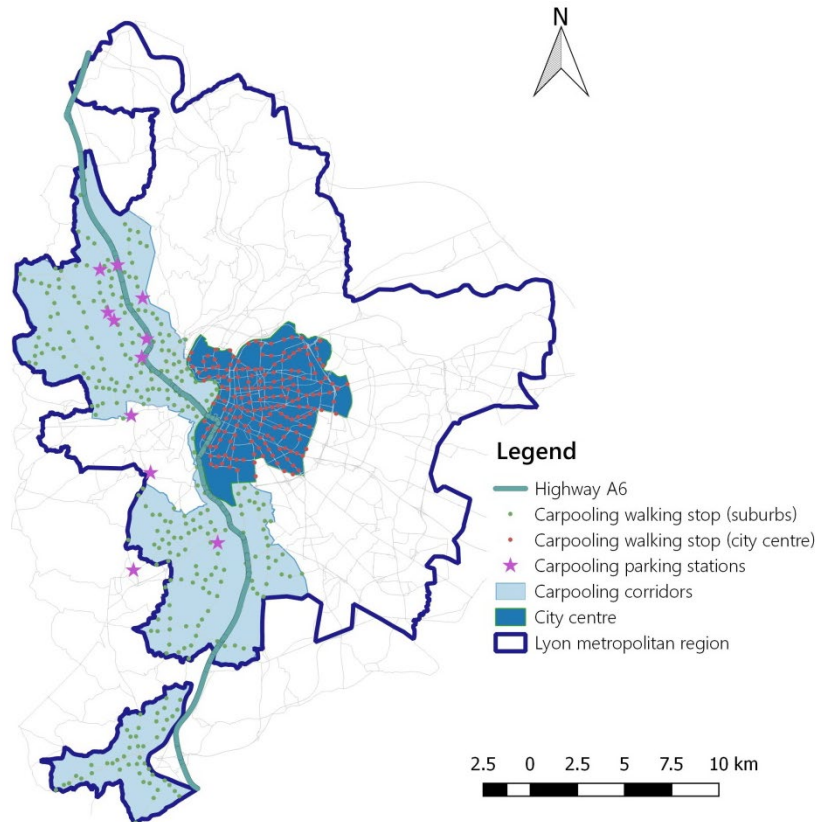
The access corridors from the A6 highway around Lyon generate approximately 13% of the region’s trips but represent 35% of the trips that take place during the morning peak period in LMR. As such, they present a very heavy daily commuting pattern that can produce congestion into and out of the city, especially when combined with the national and regional through-traffic. Moreover, public transport towards the city is mostly provided by bus services and some regional rail connection. This leads to a car modal split in these corridors that is about 20% higher than the regional average. These factors testify to a potential benefit of shared car use in these zones.

Scenario 4 simulated the deployment of an optimised and centrally dispatched carpooling service along the section of the A6 highway that provides access to the city of Lyon. Two corridors were defined: West–City centre and South–City centre. The goal was to encourage car drivers to share the ride and reduce traffic congestion to and from the city centre during peak times (see Figure 18).

The scenario allowed for two kinds of access modes for carpooling. One was by car to dedicated parking stations near the highway access points where riders could park their cars and meet the carpool driver. The passengers could also decide to walk to predefined pick-up locations in the area. The model’s taxi-bus

stops were used for this purpose. Figure 18 also shows the catchment area of customers considered and the location of parking stations along the A6 access points.

Figure 18. Map of the carpooling corridor's components along the A6 highway



Source: ITF, map tiles by QGIS.

The potential attraction of this alternative was subject to the modal preference stated by survey respondents under certain conditions. The estimated potential modal willingness to change from car to the carpooling alternative was estimated at 14%. The algorithm tried to match these trips to produce carpooling rides.

The carpooling services tested solely along this corridor were divided into two possible configurations. If available carpooling services to or from the city centre did not match the user's desired trip parameters 1) the trip was not served, or 2) service was replaced by a taxi-bus or shared taxi.

This test intended to measure the possibility of a safety net for carpooling if the pool could not be formed. This trial explored the concept of MaaS that is currently expanding and diversifying around the world, with some initial cases of success in reducing car ownership and use (Durand et al., 2018).

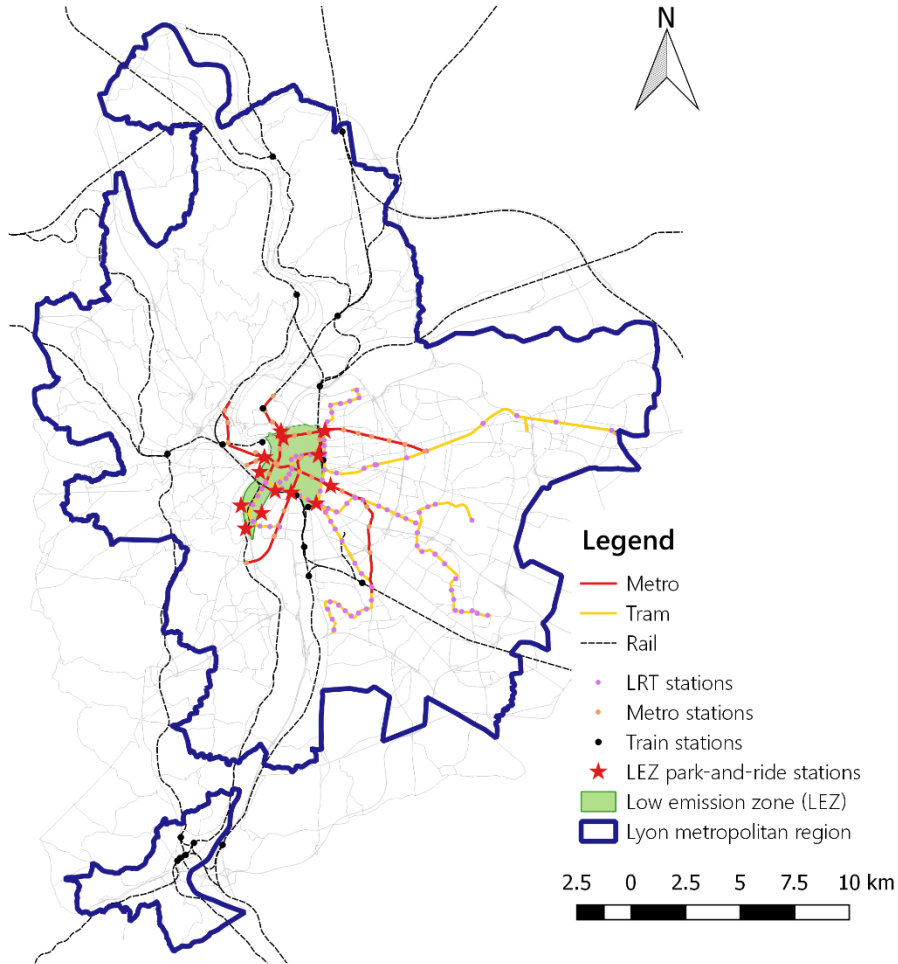
Low emission zone scenario

Scenario 5 tested the impact of banning private cars within an LEZ for a whole day while providing different levels of car replacement outside of the LEZ. The LEZ boundaries were established based on the

maximisation of the possibility for car drivers and passengers to transfer to public transport at park-and-ride stations.

The model was tested using a geographical boundary with constraints on private car circulation with 15 park-and-ride stations at which users could transfer from private cars to PT or shared modes (Figure 19).

Figure 19. Definition of the low emission zone tested



Source: ITF, map tiles by QGIS.

All the trips made by buses and private cars within the LEZ boundaries at the time of the study were replaced. Rail and LRT trips were kept or substituted with shared modes given the estimated preferences of each user and trip. Additionally, 20% of the car users affected by the LEZ restrictions shifted to shared mobility from their origin instead of parking at the LEZ border. Some car users who did not cross the LEZ borders also shifted to the shared modes (20%).

General indicators and performance measures were calculated for the shared mobility services in all of the scenarios. The general indicators included major mobility outcomes, such as vehicle- and passenger-kilometres travelled by different modes, environmental performance (CO₂ emissions), and congestion levels. Changes in modal split, PT ridership, access and connectivity were also measured.

The operational performance measures included indicators general to the entire transport system and indicators specific to the shared modes. Operational performance indicators of the shared modes were calculated for all the scenarios and included the average occupation of vehicles and the number of vehicles needed to supply the demand.

Additionally, in-depth analysis was carried out for four selected scenarios. It included more detailed indicators and maps showing congestion levels for each link, and passenger-kilometres by different modes during the peak hours by grid. Additional operational performance indicators were estimated for the shared modes in the selected scenarios. They included waiting-times distributions, time-loss distributions, kilometres per day per vehicle, average occupation of vehicles along the day, percentage of upgraded passengers per day, dynamics at shared mobility stations, dynamics of boarding and alighting shared vehicles at heavy public transport stations, and the number of kilometres travelled by empty shared mobility vehicles.

Impact of shared mobility

This section presents the results of the agent-based microsimulation model for the pre-set scenarios. The results include indicators of the overall performance of the transport system after the introduction of the shared modes and associated operational performance indicators. The indicators include aggregated indicators on passenger-kilometres (pkm), vehicle-kilometres (vkm), mode shares, fleet size, emissions, accessibility and connectivity measures, congestion levels in absolute values and in comparison to the baseline scenario that represents the current mobility. The operational performance indicators include the average vehicle utilisation and the fleet size required to serve the demand for the shared modes. The major differences among the scenarios are highlighted for further policy insights discussion.

The section also includes more detailed analysis for four scenarios, which were selected based on an assessment of the initial results from the original five scenarios. Most of the indicators in this analysis are disaggregated to the level of grid cells, road network links and time of the day.

The section also contains a brief comparison of the main indicators with the ones obtained from other mobility case studies: Lisbon metropolitan area (ITF, 2016); Helsinki metropolitan area (ITF, 2017b); Auckland metropolitan area (ITF, 2017a); and the Greater Dublin Area (ITF, 2018).

Major mobility outcomes

The indicators used to assess the overall performance of the transport system in the study area are CO₂ emissions, the congestion levels and vkm. Table 10 displays the changes in these indicators compared with the baseline scenario. The relative values show the significant benefits that each scenario with shared mobility brings to the transport system. The congestion is calculated as the average of volume to capacity ratios for the actively used links. The CO₂ emissions are calculated as a sum of the emissions for each mode (Annex D contains the initial values used in the calculations). It should be noted that the congestion changes presented in all scenarios with a partial replacement of bus do not include the reduction of congestion due to fewer bus vehicles. However, this reduction is negligible since the bus share in terms of traffic volumes is relatively small. Finally, Table 10 shows how the fleet of motorised vehicles can be reduced with the presence of shared mobility. In the full-car replacement scenarios, shared modes can provide the same mobility in the LMR with less than 13% of the current fleet of motorised vehicles. This value is much higher than in previous reports as the carpooling system modelled requires retaining part of the existing private car fleet. The run of the model with no carpooling solution would produce car fleet requirements under 5% of the current car fleet.

The results show that scenario 1, which fully replaces all private car and bus trips, gives maximum benefits across all four indicators. It is followed by two other scenarios with a 20% car replacement rate (Sc. 2 and Sc. 3), where retaining highly frequent bus routes seems to lead to good outcomes. Results are more limited for the carpooling corridor scenario (Sc. 4), especially in the ability to reduce car fleet. Nevertheless, a reduction of 4% in CO₂ emissions with a targeted measure in one corridor shows that this solution can be attractive in some corridors with strong and dispersed commuting patterns. The LEZ in scenario 5 produces the least benefits of all the scenarios, with only slight reductions in vkm, congestion and CO₂ emissions compared to the baseline. The reason is that park-and-ride may increase the concentration

of motorised vehicles in the smaller streets around the LEZ border as prospective carpoolers search for a parking space in order to use the service. The only benefit is that a reduction of private car use creates less need for on-street parking in the city centre, resulting in freed street space that may be reallocated.

Notable in scenarios 2 and 3, wherein 20% of the car trips in the LMR were replaced, is that reductions in vkm and CO₂ emissions were slightly higher than in the carpooling scenario (Sc. 4). That is, the same level of the environmental benefits can be achieved affecting a lower number of the current car users in Sc. 2, focusing on the areas with greater opportunity for sharing a ride. However, the corresponding reduction in the congestion levels in Sc. 4 with the same levels of traffic congestion reduction is not able to reduce so CO₂ as significantly. This suggests there is a need to balance environmental and congestion objectives. The results obtained for the rest of the scenarios also show that targeting car users is crucial to reduce congestion (see Table 10 and Figure 22).

Table 10. Changes in vehicle-kilometres, CO₂ emissions, congestion, and fleet requirements compared to the baseline (%)

Scenario	Vkm	CO ₂	Congestion	Motorised vehicle fleet (equivalent private car vehicles) (%)
1	-54.0	-50.6	-47.6	-87.8
2	-9.8	-11.6	-15.5	-18.9
3	-11.2	-12.4	-16.3	-20.9
4	-4.6	-4.2	-13.7	-0.1
5	-2.8	-0.9	-5.8	-17.8

Note: To transform to the equivalent car vehicles, vehicles of the motorised modes are weighted by the following factors: conventional taxi: 1; shared taxi: 1.1; taxi-bus (8 seats): 1.3; taxi-bus (16 seats): 1.5; bus: 3.

Table 11 examines the pkm by mode and Table 12 the number of trips by mode. Analysis of the reduction of car travel by scenario shows that the removal of 20% of car travel produces very similar outcomes in terms of pkm, evidence that car use drops everywhere and trip length is consistent with the pre-existing average car activity profile. Full replacement of car and bus mobility also affects LRT ridership as users also lose connecting modes, showing a strong intermodality between bus and LRT in the region.

Rail and metro ridership also increase, but mostly for short trips within the city and for direct routes once fed by shared mobility services. This fact produces a slight increase of 12% in pkms but an impressive 83% increase in the number of users. This large increase would generate stress at stations and interface points. Park-and-ride stations would have to be efficiently designed to ensure the required throughput and safe integration with users of non-motorised modes.

Scenario 1 results show that shared taxis became more relevant and predominant when serving the least accessible persons in the study area, whereas taxi-buses operated with difficulty under the established minimum load threshold. Scenarios 2 and 3, which targeted the 20% early adopters of shared mobility among private car users, led to more balanced outcomes between shared taxis and taxi-buses. Scenario 5 produced primarily taxi-bus services at the LEZ parking and entry points and at public transport transfer points.

Table 11. Passenger-kilometres and changes compared to the baseline scenario

Scenario	Pkm, thousands						Pkm changes, 100%			
	Shared taxi	Taxi-bus	Car *	Bus	LRT	Rail or metro	Car *	Bus	LRT	Rail or metro
Baseline	-	-	10 391	855	410	1 011	-	-	-	-
1	7 326	3 264	828	-	322	1 133	-92.0	-100.0	-21.5	12.0
2	1 693	1 457	8 299	-	397	1 037	-20.1	-100.0	-3.1	2.5
3	1 604	1 046	8 298	166	405	1 052	-20.1	-80.6	-1.0	4.1
4	-	-	9 916	855	410	1 091	-4.6	0.0	0.0	7.8
5	82	628	10 383	855	414	1 076	-0.1	0.0	1.1	6.4

* Includes carpooling pkms.

Total pkm of motorised modes, i.e. the sum of car, bus and shared mode pkm, is higher in the scenarios with higher rates of car replacement. This is expected due to the level of detours made by the shared vehicles. Total pkm of the motorised modes grows approximately 10% for the scenario with 100% car and bus replacement (Sc. 1) and approximately 5% for the 20% car replacement scenarios (Sc. 2 and Sc. 3). The carpooling scenario (Sc. 4) is the only one that leads to a drop of car-related pkms (approximately 5%). As Table 10 shows, despite of the increase in pkm, the scenarios with a larger proportion of shared modes deliver more benefits for the city in terms of the total vkm and CO₂ and congestion reduction, due to the higher occupancy of the vehicles used in these scenarios.

Analysing the pkm results together with the number of trips per mode allows for a better understanding of the impacts of the shared modes on mobility in each scenario. For example, an examination of Table 11 and Table 12 shows that LRT pkm lowers by around one-quarter while the number of LRT trips increases 83%. This means that, on average, LRT trips become shorter and involve no transfers, which is similar to railway ridership.

Table 12. Trips per mode, by thousands

Scenario	Shared taxi	Taxi-bus	Carpooling	Car	Bus	LRT	Metro	Rail
Baseline	0	0	0	1 263	196	97	278	4
1	691	474	62	0	0	138	509	13
2	192	194	11	961	0	106	330	8
3	177	129	11	1 399	63	105	324	6
4	0	0	10	1 253	196	97	278	4
5	523	259	9	1 080	196	103	319	5

Around 3.2 million trips took place within the LMR on an average workday in 2015. Around 800 000 (26% of the whole day) took place during the morning peak period from 07:00 to 10:00, and one million during the afternoon peak from 16:00 to 19:00 (27% of the whole day). The majority of the trips were by private car (42%), closely followed by walking (38%) and public transport (18%), as shown in Table 2. The mode shares within the city of Lyon were slightly different, with a lower car share of 17% and non-motorised modes accounting for approximately 61% of the trips.

The estimated mode share of private car was 41.5% when taking into account all modes, including walking and cycling. If only motorised modes are included, private cars represent more than 69% of the trips (see Figure 20). In the scenarios with larger adoption rates of shared mobility, the total share of rail, metro and LRT increases compared with the baseline, while this does not always hold for pkm.

Table 13 presents new mode shares and new average trip attributes for transport system users depending on the mode they use currently for the scenarios. While the total number of trips in each scenario remains constant, the results presented in Table 13 account twice for trips which contain segments by different modes. Therefore, the LEZ scenarios present the largest total numbers of trips as many of the current car users in these scenarios drive their cars until the LEZ border and then change to another mode.

Figure 20. Motorised mode shares in different scenarios

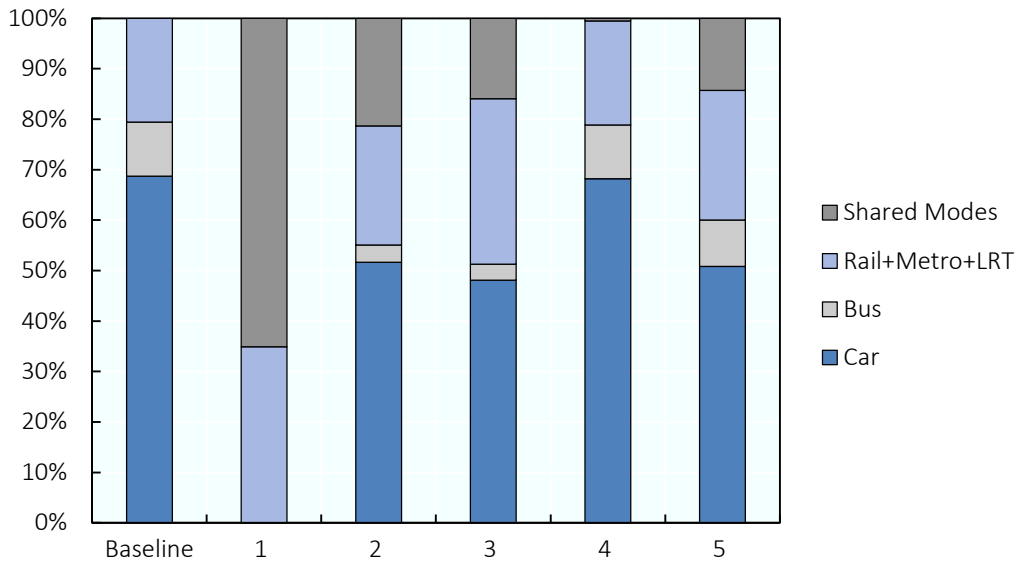
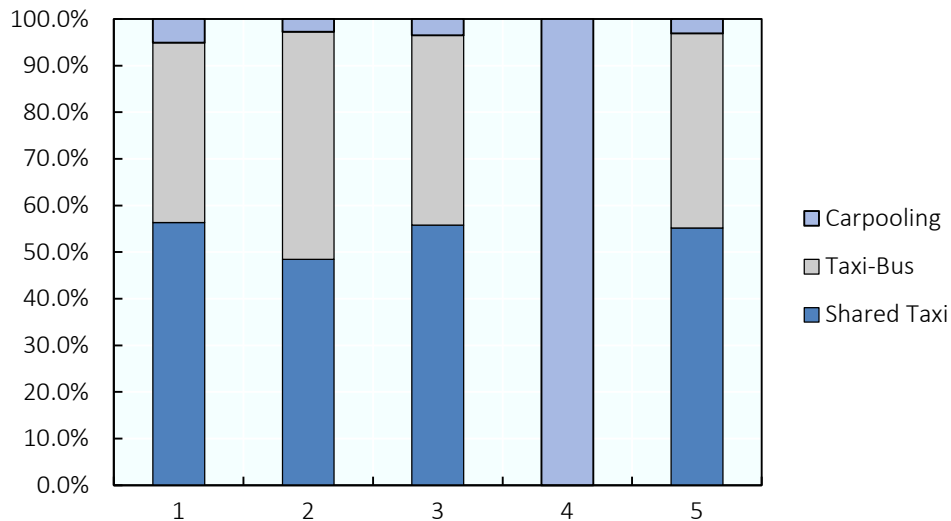


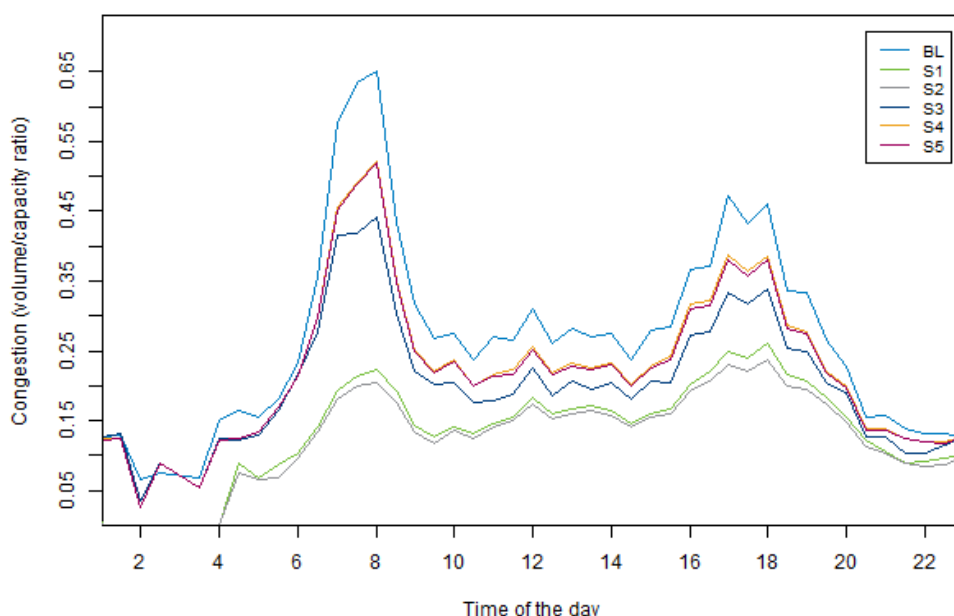
Figure 21. Mode share between taxi-bus and shared taxi in different scenarios



The percentage of trips carried by a shared mode shows how the transport system is efficient in terms of sharing (Figure 22). The larger share of taxi-buses means that there is a greater number of trips that use a taxi-bus which requires a vehicle occupancy rate of more than 40%. All of the scenarios with no spatial differences in car replacement rates (Sc. 1-3) or single carpooling scenario have a greater use of shared taxi than of taxi-bus.

Finally, measuring the congestion levels during the day provides more information about the performance of the transport network at different hours. Figure 22 presents the congestion levels calculated as an average volume to capacity ratio across all active links in the LMR (more than 50 vehicle movements in one hour). In accordance with Table 10, all the scenarios lead to a decrease in congestion compared with the baseline scenario, with the scenario with full car replacement (Sc. 1) delivering the largest reduction. The difference is greatest during peak hours, especially in the morning, since congestion is heaviest at this time, as the baseline shows.

Figure 22. Congestion per time of the day



Changes in access and connectivity

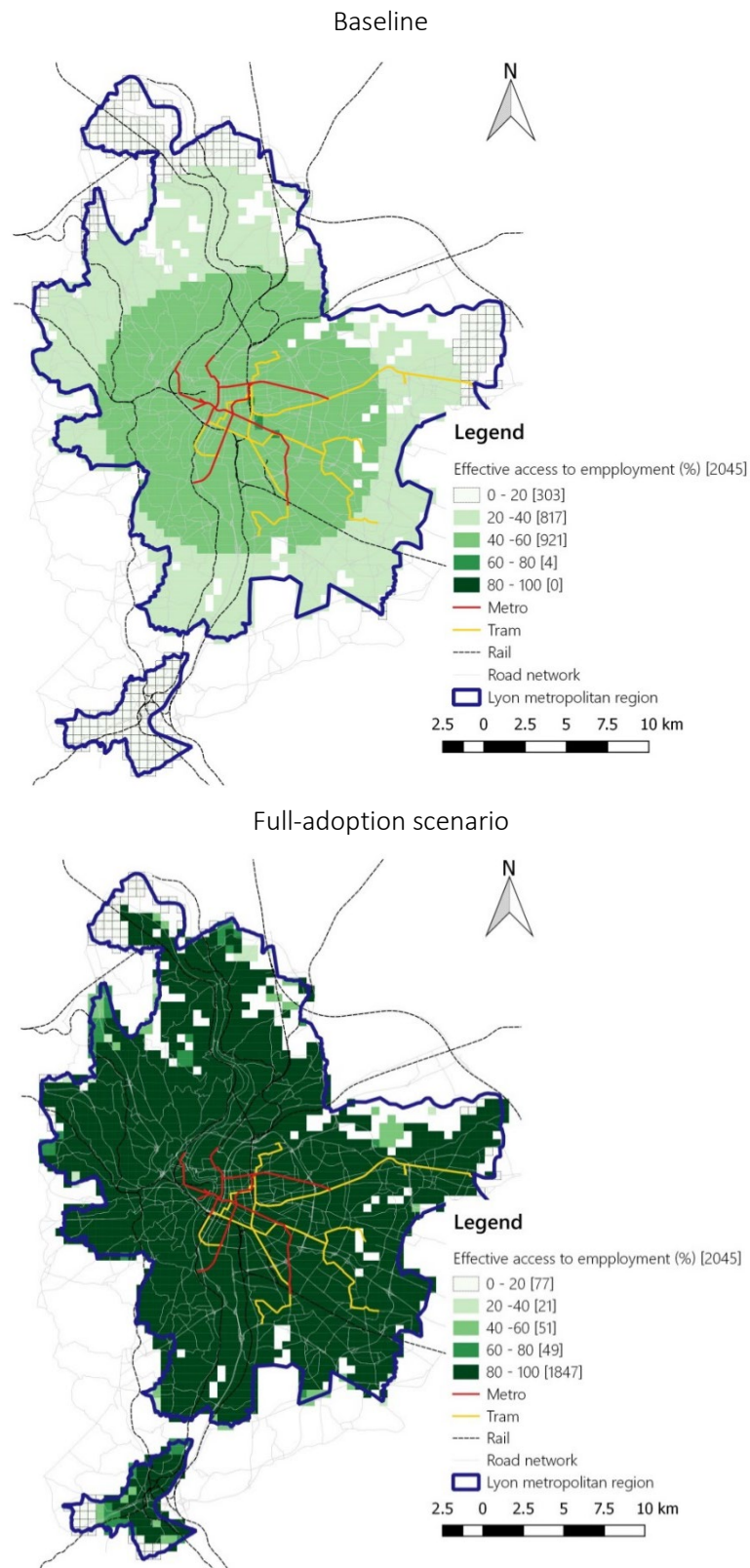
Accessibility and connectivity are important measures for benchmarking across scenarios and case studies a transport system’s effectiveness. Accessibility is the ease of access to the amenities in order to perform different kinds of activities. Connectivity is the performance of the transport system in terms of time, speed, number of transfers, etc. for an average trip. The accessibility levels along a continuum of perception can be presented by means of effective access. Effective access takes into account the travel time related to a particular origin-destination pair using the Attraction Decay Curve (Annex E).

The comparison of the effective access in the LMR for the full-replacement scenario (Sc. 1) and for the baseline scenario shows that shared mobility improves access significantly and provides a more even distribution of access across the study area (Figure 23).

In the baseline scenario, the areas in the centre of the LMR with good proximity to metro and LRT have much better access than the more remote ones. In the case of full adoption scenarios, access increases for the users from the central part of the LMR and for those from the more remote parts. The number of grid cells with very low effective access reduces substantially, from 303 to 77. Effective access becomes greater than 60% for the residents of almost 1 900 grid cells, when before it was limited to four cells in the city centre.

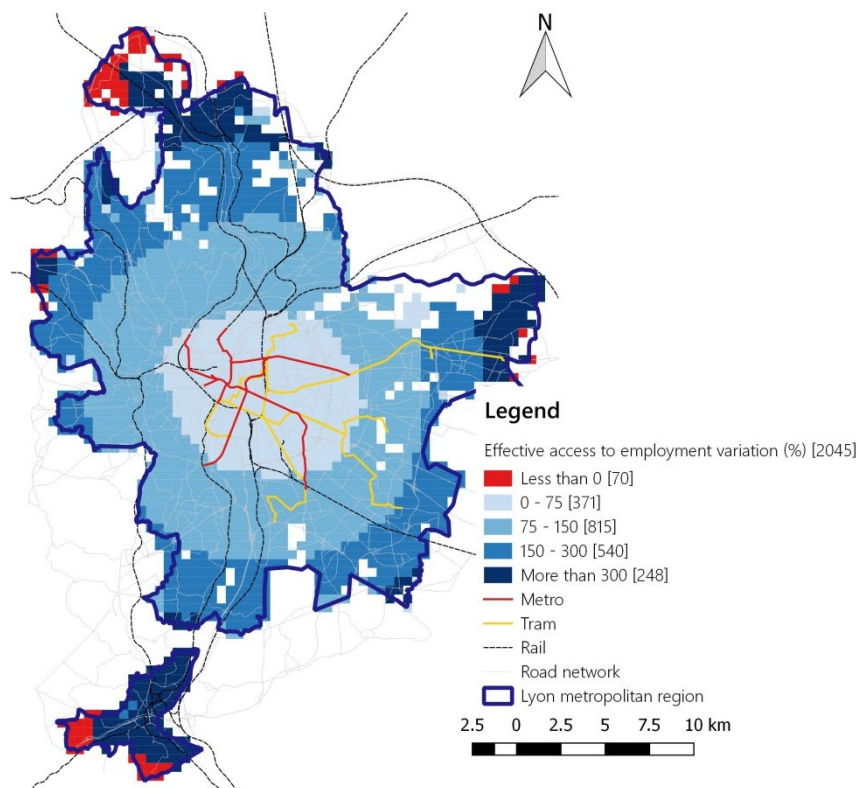
The increase in effective access due to the adoption of shared mobility is higher for more remote parts of the LMR than for the central part. Figure 24 shows the ratio of the effective access of the baseline scenario to that of the full-replacement scenario (Sc. 1). The change in accessibility is approximately proportional to the distance from the city centre. The average effective access for the baseline scenario across all grid cells is 40%, and 91% for the full adoption scenario, which means that the full adoption scenario would provide twice as many people in the LMR with good access. There are very few areas that show a decrease in access (70 cells). When compared with Figure 23, however, these are the areas that had low levels of access in the baseline scenario. Therefore, the observed absolute negative is negligible.

Figure 23. Effective PT access to population, baseline and potential of the full adoption scenario



Source: ITF, map tiles by QGIS.

Figure 24. Variation of effective public transport access to population, as a ratio baseline and potential of the full adoption scenario



Source: ITF, map tiles by QGIS.

Most of the scenarios show some increase in average travel time for the current car users and a decrease for the current PT users (Table 13). The travel time increase for car users is a consequence of the system design which allows a maximum detour time of 15 minutes in addition to the original car travel time, leading to an average increase of seven minutes. This fact shows that additional benefits have to be understood by car users to ensure capturing a significant share of those who noted their interest in the stated preferences survey. This will allow the shared mobility service costs to be attractive to customers.

Table 13. New mode shares and new average trip attributes for transport system users depending on the mode they use currently for the scenarios

Scenario	Car users	PT users				Car mode share (%)	PT and shared mobility mode share (%)
	Travel time (in minutes)	Total travel time (in minutes)	Waiting time (in minutes)	Access time (in minutes)	Number of transfers		
Baseline	19	45	8	27	0.62	41	18
1	26	38	7	10	0.60	0	55
2	23	39	7	17	0.49	35	25
3	16	40	6	19	0.49	35	24
4	19	47	8	26	0.63	40	19
5	18	42	7	19	0.53	32	28

The total travel time decrease for the PT users also includes a decrease in access time and wait time, which often has more value than on-board time for users (Balcombe et al., 2004). Thus, the shared modes lead to a more even distribution of the average trip attributes across the residents of the study area and users of different modes. These attributes are connectivity indicators serving as a proxy for the quality of service.

The last two columns of Table 13 present the current mode share of car and PT and, therefore, provide an indication of how many users are affected by the changes. Only scenarios 3 and 5 lead to a reduction in the average travel time for the current car users. The gains in these two scenarios are potentially due to the reduced congestion levels resulting in faster trips for the remaining 80% of car trips. It is noteworthy that the average travel time of all PT users also reduces in these two scenarios. Scenario 1, with full replacement, leads to the shortest average travel time for the current PT users but also to the longest one for the current car users. This is due to all current car users switching to the shared modes and all the PT users switching to faster trips by shared modes or rail-based modes. Scenario 2 results in similar average-travel-time improvement for current PT users since all current bus trips are replaced by taxi-bus services. However, replacing all buses does not compensate in terms of CO₂ emissions as mentioned above.

Operational performance

Operational performance indicators characterise the efficiency of the system from the operator's point of view. Table 14 presents the average occupancy of the shared modes and the size of the required fleet by vehicle type. The vehicle types include shared taxis, taxi-buses with eight and 16 seats and private vehicles used in carpooling.

The average occupancy is relatively stable across the scenarios, with a smaller load factor of shared taxis when not in the full adoption scenario. The dispatcher allocates shared taxis to users who request that mode, but also to users who order a taxi-bus but whose trip cannot be fulfilled because it does not meet the 40% minimum occupancy rate. Hence, the scenarios with lower levels of replacement of current motorised trips have a lower occupancy level in shared taxis. Taxi-buses have slightly better average occupancy rates in the LEZ scenario as it is easier to combine the users into shared vehicles in the denser area. Regarding carpooling, the average party size is fairly stable across all scenarios.

As expected, scenarios with larger motorised-modes replacement rates require larger fleets of vehicles to meet the demand for shared mobility. The full replacement scenario (Sc. 1) would require more than 53 000 vehicles (12 000 for a shared mobility fleet), which is the largest fleet size. This is followed by scenario 2, which retains all bus services and assumes a 20% car replacement, which would require 12 000 vehicles (4 200 for a shared mobility fleet). Scenario 5 with the LEZ would require the least amount of motorised vehicles (less than 9 000).

Fewer vehicle types would be required to supply the new shared services in the LMR. SP surveys showed that eight-seat vehicles would be more commonly used than 16-seaters. This opens the possibility of using the same vehicles for both the shared taxi service and the taxi-bus service. The services' attributes – the required distance from a stop, the need for pre-booking, and more flexible detour and waiting times for customers – would differentiate them. Therefore, a more optimal allocation of vehicles would be possible.

Table 14. Estimates for number of vehicles and occupancy

Scenarios	Average occupancy (passengers)				Number of vehicles			
	Shared taxi	Taxi-bus 8	Taxi-bus 16	Carpooling	Shared taxi	Taxi-bus 8	Taxi-bus 16	Carpooling
1	2.3	4.0	8.6	2.4	8 745	729	2 252	41 544
2	1.8	3.9	8.7	2.3	2 548	492	1 181	7 478
3	1.9	3.9	8.6	2.3	2 216	365	766	7 535
4	-	-	-	2.3	-	-	-	6 394
5	1.8	4.0	8.7	2.3	1 661	124	472	6 141

Comparison with other ITF shared mobility case studies

The results observed for the LMR suggest similar positive outcomes to the original ITF study performed for the Lisbon metropolitan area (LMA) (ITF, 2017c) and other case studies (ITF, 2017a; ITF, 2017b; ITF, 2018). Table 15 presents a brief comparison between the full replacement scenarios of these studies.

Table 15. Comparison of results with the previous shared mobility studies

Case studies, full replacement	% Reduction to baseline	
	Vkm (weighted)	CO ₂ emissions
Lyon metropolitan region	54	51
Greater Dublin Area	38	42
Helsinki metropolitan area	23	28
Auckland metropolitan area	51	54
Lisbon metropolitan area	48	62

The differences in the results are driven by various factors including the size and the density of the study areas, spatial configurations, user preferences, transport infrastructure and land use. The high density of the LMR and the good public transport coverage produce very interesting results for the region when compared to other case studies. The population density in the LMR determines the vehicle occupancy levels in shared taxis and the share of the population that can be served by taxi-buses. This fact, together with the differences in the initial mode shares explains the lower vkm elasticity with respect to private car mode share change (above 1 in the LMR as in the LMA). As Table 15 shows, taxi-bus has a significantly higher mode share than shared taxi in the LMA, whereas in the LMR it is more balanced, although favourable to the shared taxi. Furthermore, the mode share of heavy public transport in the LMA in the full replacement scenario is significantly higher. In terms of CO₂ emissions, as the car fleet in Lisbon is older, the CO₂ reduction is much greater than the reduction in vkm while the opposite is true in Lyon due to a more recent private car fleet.

Table 16. Mode shares in the shared mobility studies

Baseline	Heavy capacity	Bus	Car	Walk + cycling
Lyon metropolitan region	12	6	41	43
Greater Dublin Area	12	20	50	19
Helsinki metropolitan area	12	15	41	32
Auckland metropolitan area	below 1	3	82	14
Lisbon metropolitan area	12	20	50	19
Full replacement	Heavy capacity	Taxi-bus	Shared taxi	Walk + cycling
Lyon metropolitan region	21	15	23	41
Greater Dublin area	7	27	36	30
Helsinki metropolitan area	16	19	32	33
Auckland metropolitan area	8	40	39	13
Lisbon metropolitan area	17	38	28	16

Detailed analysis of selected scenarios

Some scenarios were selected for more detailed analysis. Among these were the further disaggregation (per grid and per link) of the indicators already produced, the estimation of parking and depots requirements, and the production of additional operational performance indicators for the shared modes. The selection of the scenarios was based on the likelihood of its implementation given the local context and also to gain a better understanding of the impacts of different phases of shared mobility adoption. The selected scenarios include:

- scenario 1 – full car and bus replacement
- scenario 3 – 20% rate of car replacement and preserved core bus network
- scenario 4 – centrally dispatched carpooling along the Highway A6 corridors
- scenario 5 – an LEZ and 20% car replacement rate for trips that start outside of the LEZ and end within it.

Scenario 1 provides a benchmark for comparison with other shared mobility case studies. It also shows the potential impacts and system performance were shared mobility deployed to the fullest extent.

Scenario 3 represents a more realistic scenario where only a portion of private car users is attracted to shared mobility services. In this scenario, retaining the high-performance bus services, and replacing 20% of private car trips results in significant vkm and CO₂ emissions reductions. The results of the stated preference survey suggest that a reduction of 20% of car trips is a plausible scenario, on the assumption that the system operates with the same level of quality as presented to the respondents in the survey choice games.

Scenario 4 explores the development of a centralised carpooling dispatch model along the A6 highway corridors with dedicated parking lots. This scenario may provide a good idea of the scale of impacts such a measure may have in a commuting corridor.

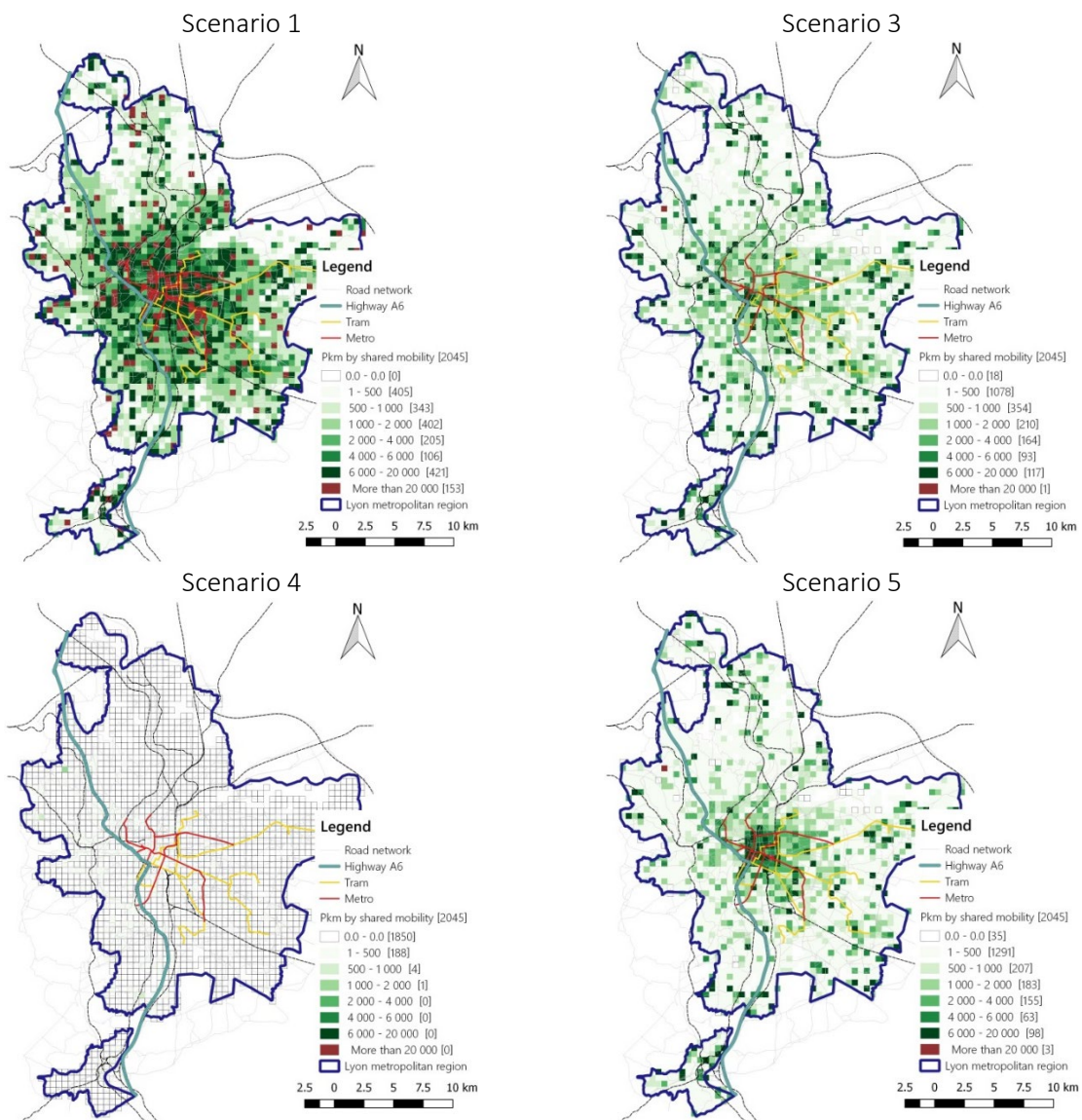
Scenario 5 estimates the performance of the transport system in the situation where spatial restrictions are applied to the use of private cars. The detailed analysis of this scenario includes additional indicators that provide insight to the need for supplementary infrastructure at the park-and-ride stations.

Scenario 2 was not tested in detail because it presents a car replacement of 20%, like scenario 3 that presented better macro indicators. Most detailed indicators for scenario 2 would be very similar to those from scenario 3 and would mainly duplicate the conclusions for the same level of car replacement.

Detailed mode share and public transport ridership assessment

The spatial distribution of the pkm generation in each grid of the study area (figures 25-28 indicates that in all the scenarios the shared modes evenly cover the area while the public transport pkm are mostly generated in the central part of the LMR. The patterns of the pkm generated by car vary substantially across the scenarios, due in large part to the presence of the LEZ. The figures enable the comparison of the generated pkm across the four scenarios with the pkm in the baseline case (Figure 12).

Figure 25. Daily passenger-kilometres by shared modes by grid of origin for the selected scenarios



Source: ITF, map tiles by QGIS.

In the case of full replacement in scenario 1, only shared mobility services, LRT, metro and rail are available. Private car and bus services are replaced completely. Most of the passenger-kilometres depart from the city centre or from remote suburban areas connected by the highway system to the city centre. The spatial distribution of the pkm by shared mobility is very similar to the spatial distribution of the pkm by car in the baseline scenario, with a slight increase of the number of grid cells generating more pkm in the case of shared mobility. Since there is no conventional available bus in Sc. 1, all the grid cells generating PT pkm are located along the rail, metro and LRT lines.

Scenario 5, devoted to carpooling along the A6 corridors, replaces a small percentage of private cars (1.3% for the city of Lyon and 8% for the whole area) commuting daily towards the city centre with carpools (see figures 25 and 26). The scale of shared mobility pkms is small compared with other scenarios. However, results show a significant reduction in congestion, mainly on the A6 highway, and a 4% reduction in CO₂ emissions due to the long distances of commutes. Figure 26 shows that some cells may generate up to 1 000 pkms of carpooling per day.

Figure 26. Daily passenger-kilometres by carpooling and by grid of origin

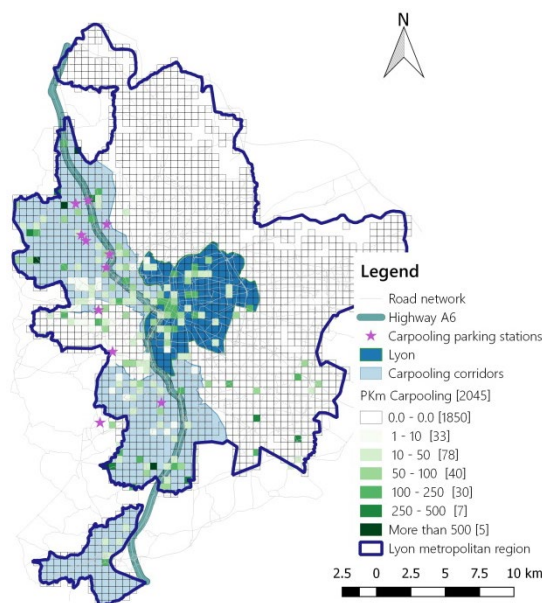
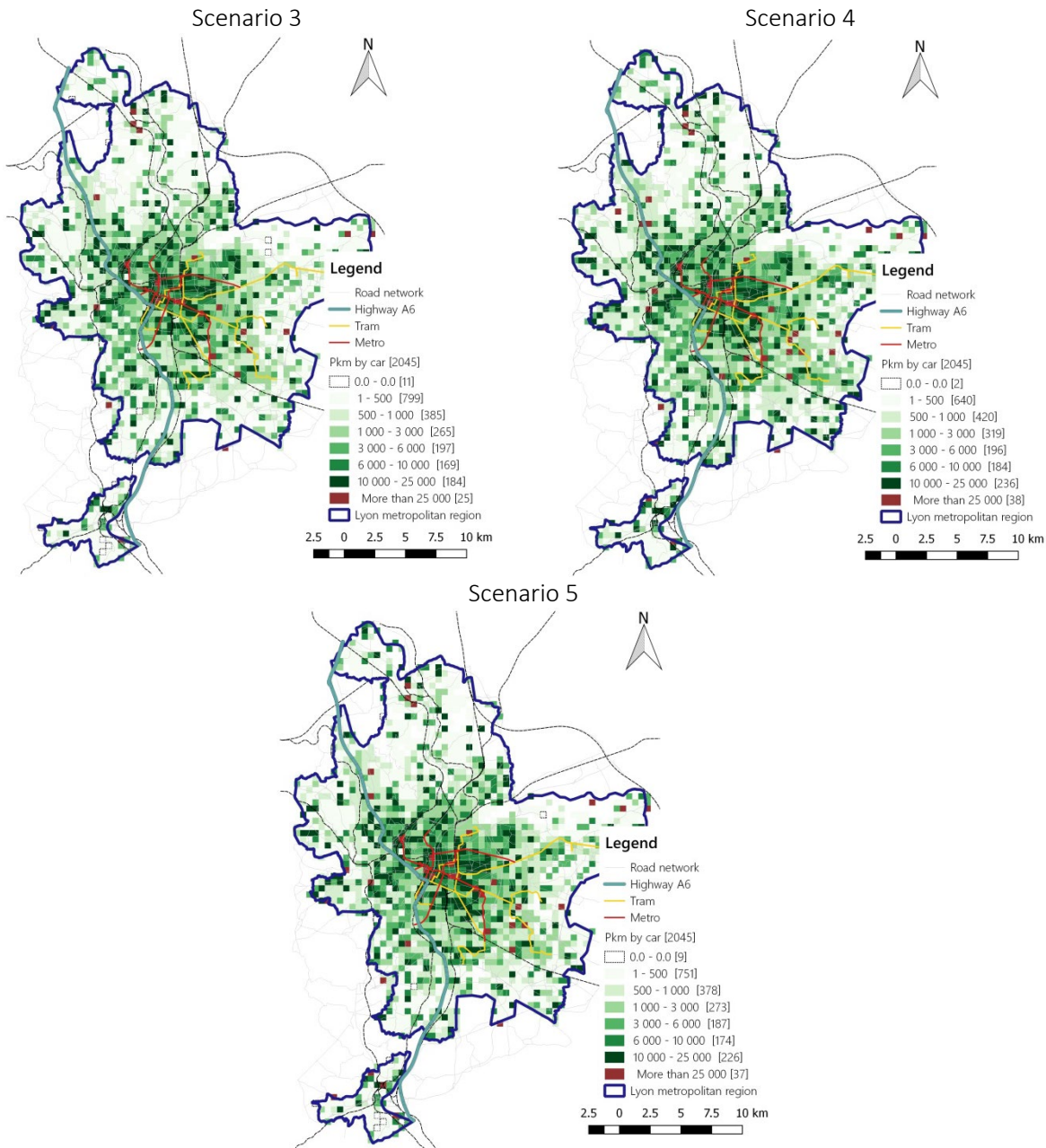
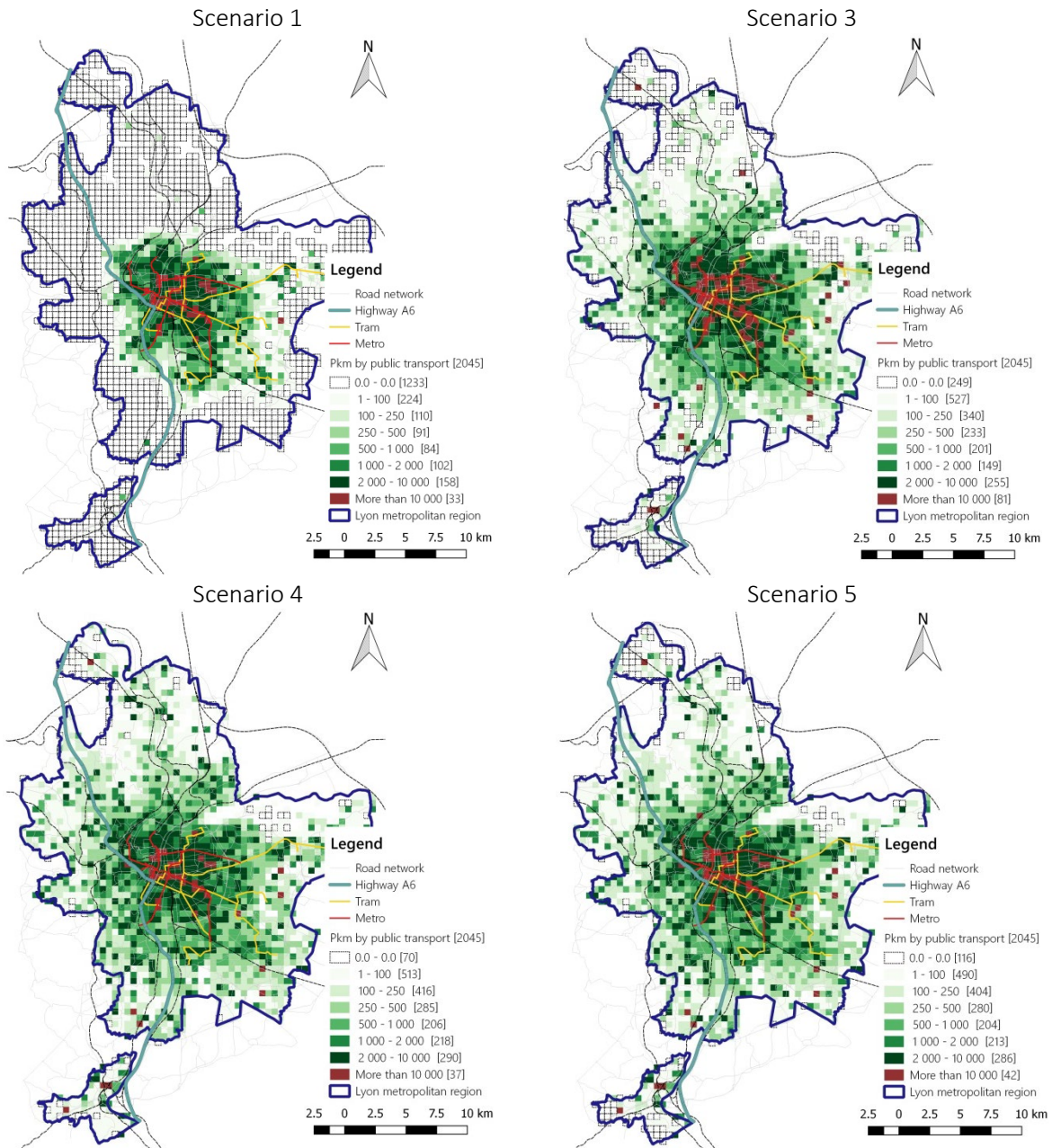


Figure 27. Daily passenger-kilometres by car and by grid of origin for selected scenarios



Source: ITF, map tiles by QGIS.

Figure 28. Daily passenger-kilometres by public transport by grid of origin for the selected scenarios



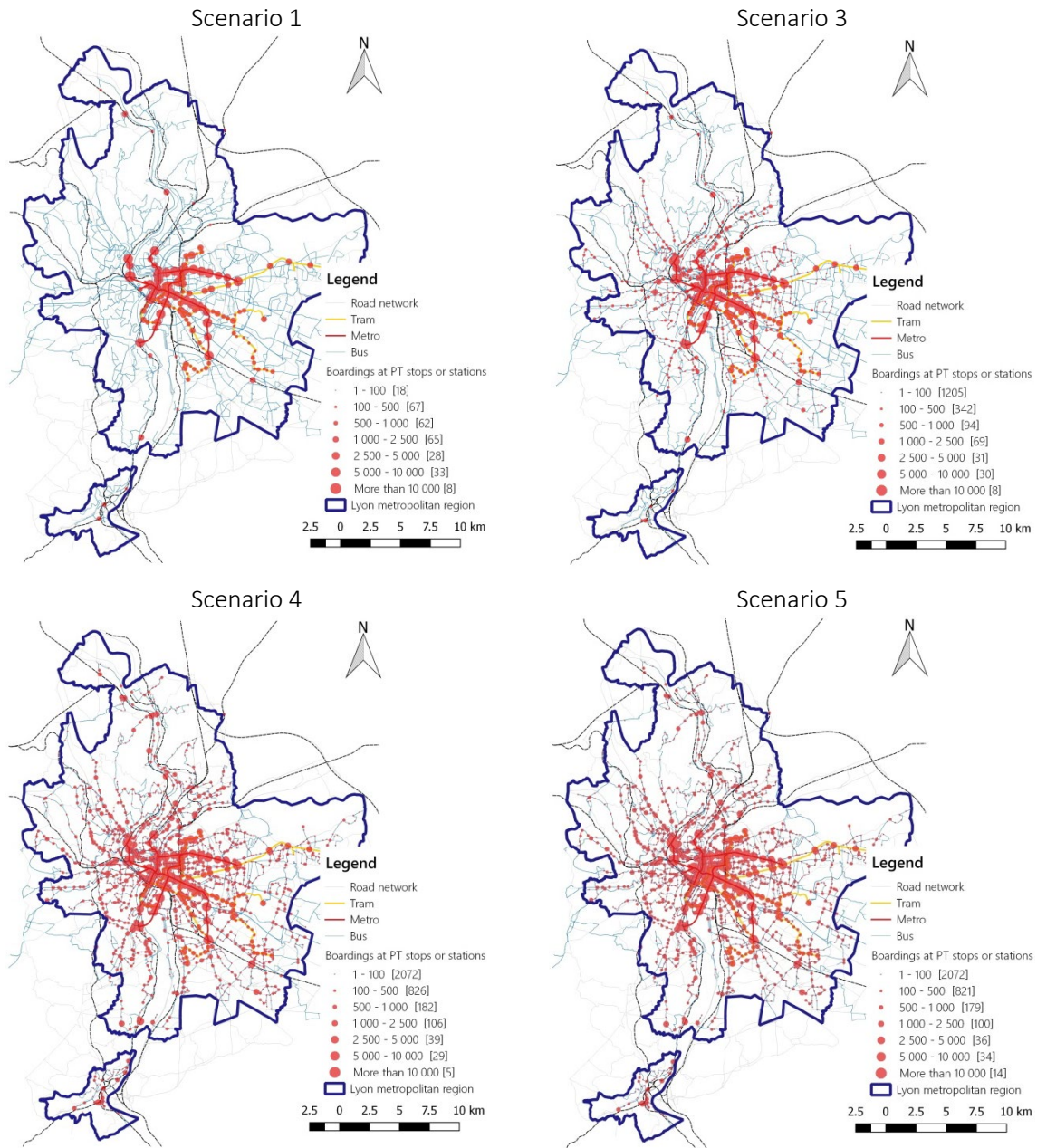
Source: ITF, map tiles by QGIS.

In scenario 3, the 20% replacement of private car trips results in the redistribution of pkm between cars, shared mobility and the heavy PT modes. There is almost 35% reduction in the number of grid cells generating more than 10 thousand car pkm compared to the baseline scenario. Most of the PT pkm are generated in the central part of the LMR and along the tramway line 3. Most of the shared mode pkm originate in the centre and towards the feeding of heavy public transport lines.

A 20% car replacement rate for areas outside of the LEZ in scenario 5 produces a substantially larger amount of shared mobility pkm within the LEZ and a similar amount of pkm in the remote areas of the

LMR, compared with Sc. 3. Private car pkm reduces substantially within the LEZ boundaries compared with the baseline scenario since the only trips which generate car pkm within the LEZ are those that originate in the LEZ and finish outside of it.

Figure 29. Ridership by number of boardings at each station for the selected scenarios



Source: ITF, map tiles by QGIS.

In all the scenarios, even those with small car replacement rates, the provision of shared mobility feeder services increases the share of metro, rail and LRT. Figures 15 and 29 show the PT ridership by number of boardings at each PT stop or station in the study area for the baseline and the selected scenarios. In scenarios 1 and 3, the number of boardings at the central stations remains similar to the baseline but

increases at peripheral stations. Scenario 5 sees an even larger increase in boardings in the periphery and at the city centre borders.

The growth increase in park-and-ride and PT ridership may lead to capacity issues at existing parking facilities and stations in some locations. Table 17 presents the spatial distribution of boarding numbers on rail, metro, bus and LRT for the baseline scenario and for the selected scenarios. In the city centre, metro and LRT ridership increase significantly in scenarios 1, 3 and 5. The introduction of the LEZ would promote significantly heavy public transport ridership in the centre with fewer transfers between metro and LRT lines. Rail decreases significantly in all scenarios. It may require better access and fewer transfers to be a competitive alternative. Users from the north, east and south areas, where metro ridership is already marginal, prefer to transfer to direct shared mobility services, favouring taxi-buses. In scenario 2, which keeps the high-frequency bus services, approximately one-third of boardings are maintained with one-fifth of the bus supply (a 66% increase in ridership productivity). These results suggest that if shared mobility is introduced, metro and LRT capacity along the corresponding lines, as well as that of the stations serving those lines, should be assessed and, probably, increased in order to ensure that they can accommodate the predicted growth in ridership, as well as an efficient interface for passengers.

Analysis of the increase in parking demand reveals similar issues. Table 18 presents the access mode shares to PT by area. Currently, access is performed almost 100% by walking. Access by car in any of the LMR areas is approximately 3%. The share of access by walking decreases as users switch to shared modes for access to rail, metro and LRT stations. In Sc. 1, more than 50% of PT boardings are a result of transfer between shared mobility and heavy public transport. However, in Sc. 3, 10% of boardings are from shared mobility modes. In the case of Sc. 5, a substantial part of trips to the city centre are performed partly by private car and partly by PT.

Table 17. Ridership by number of boardings on rail, metro, bus and LRT by area, baseline and selected scenarios compared with baseline

Area	Baseline (passengers, thousands)				Scenario 1 (variation %)				Scenario 3 (variation %)				Scenario 4 (variation %)				Scenario 5 (variation %)			
	Rail	Metro	Bus	LRT	Rail	Metro	Bus	LRT	Rail	Metro	Bus	LRT	Rail	Metro	Bus	LRT	Rail	Metro	Bus	LRT
West area	5	54	119	0	-27	54	-100	0	-25	10	-64	0	-4	-2	0	-12	35	0	0	
North area	8	9	44	0	-56	16	-100	0	-52	-1	-72	0	0	-1	0	-45	4	0	0	
East area	0	8	37	27	0	0	-100	-43	0	6	-77	-4	0	-1	0	0	14	0	0	
South area	13	17	65	19	-83	-18	-100	-13	-35	-5	-87	-2	-2	-3	0	-13	6	0	4	
City centre	10	314	106	100	-59	62	-100	28	-35	9	-61	8	-4	-1	0	23	41	0	43	
Total / Average	36	402	371	146	-62	55	-100	10	-37	8	-69	4	-2	-2	0	-10	37	0	30	

Table 18. Access mode shares to public transport by area (%), baseline and selected scenarios

Area	Baseline (access %)				Scenario 1 (access %)				Scenario 3 (access %)				Scenario 4 (access %)				Scenario 5 (access %)			
	Walking	Car	SM		Walking	Car	SM		Walking	Car	SM		Walking	Car	SM		Walking	Car	SM	
West area	97	3	0		32	0	68	90	0	10	98	2	0	88	6	5				
North area	92	8	0		46	0	54	93	1	6	93	7	0	98	1	2				
East area	100	0	0		75	0	25	98	0	2	100	0	0	98	0	2				
South area	97	3	0		60	0	40	96	0	4	98	2	0	97	0	3				
City centre	96	4	0		44	0	56	88	1	12	97	3	0	72	15	12				
Average	97	3	0		44	0	56	90	1	10	97	3	0	81	11	9				

Quality of service

Detailed analysis of the scenarios shows that shared mobility can provide quality service to users, even despite waiting and detour time. Table 19 presents the statistical distribution of waiting time for shared modes by distance band for each of the tested scenarios. In all tested scenarios, the shared taxi delivers very good performance across all the distance bands, with less than 25% of the customers waiting more than five minutes. The taxi-bus delivers inferior performance across the indicators reported. Average waiting time for the 75th percentile is 10-17 minutes for all the scenarios. However, the indicator for taxi-bus does not represent a waiting time at the stop, but a time deviation from the reported intended boarding time. Even if the boarding time is delayed 10-15 minutes, the user is notified and can start walking to the taxi-bus stop later. Carpooling operation also shows a stable performance that leads in 75% of the cases, with delays under ten minutes.

Table 19. Statistical distribution of waiting time (min) by travel distance class and scenario

Mode	Travel distance	Scenario 1			Scenario 3			Scenario 4			Scenario 5		
		25th perc.	Median	75th perc.	25th perc.	Median	75th perc.	25th perc.	Median	75th perc.	25th perc.	Median	75th perc.
Shared taxi	< 2 km	1	1	2	1	1	2	-	-	-	1	1	2
	[2, 5] km	1	1	2	1	1	2	-	-	-	1	1	2
	[5, 10] km	1	2	4	1	2	3	-	-	-	1	2	3
	>10 km	1	2	5	1	2	4	-	-	-	1	2	4
	Average	1	1	2	1	2	3	-	-	-	1	2	3
Taxi-bus	< 2 km	2	5	10	2	5	10	-	-	-	0	1	6
	[2, 5] km	6	12	16	6	13	17	-	-	-	3	7	12
	[5, 10] km	11	15	18	11	15	18	-	-	-	4	9	13
	>10 km	11	15	18	12	15	18	-	-	-	4	9	13
	Average	7	12	16	9	14	17	-	-	-	2	6	10
Carpooling	< 2 km	5	8	11	5	8	11	5	8	11	5	7	10
	[2, 5] km	5	8	10	5	8	11	5	8	11	5	8	11
	[5, 10] km	5	8	10	5	8	11	5	8	11	5	8	11
	>10 km	5	9	11	5	9	11	5	9	11	5	9	11
	Average	5	8	10	5	8	11	5	8	11	5	8	11

Another key indicator of shared mobility performance is the total detour time, which is the average time spent picking up and dropping off other passengers along the route (Table 20). It is calculated as the sum of waiting time at each stop and the additional travel time for a journey compared to that of a private car travelling directly. A constraint on total detour time is set in the dispatch algorithm for the shared services. This constraint varies as a function of the travel distance.

In the case of shared taxi, the results show that for trips longer than ten kilometres the deviation from the private car on-board time can exceed ten minutes. In the case of the small LEZ scenario (Sc. 5), the indicator has smaller values since trip density is relatively high in the city centre and it is easier to match

the rides. The scenario with a 20% car replacement rate (Sc. 3) leads to the longest average detours since the probability of ride-matching is smaller.

Detour times for taxi-buses are significantly higher than for the other modes, but they comply with the constraint of maintaining a commercial speed of 15 km/h for each individual trip. In all four scenarios, detour delays exceed 35 minutes for 25% of long trips when compared with direct travel by private car. In some cases, this means doubling current private car travel time but still greatly outperforming the current public transport options in very remote areas for long trips. The average value for the 75th percentile is between 23 and 25 minutes, depending on the scenario. It indicates that in 25% of the cases a client might be delayed by 23 minutes or more when compared with the travel by private car. As in the previous indicator, carpooling performance is quite stable for all scenarios achieving good performances by design.

Table 20. Statistical distribution of detour time (min) by travel distance class and scenario

Mode	Travel distance	Scenario 1			Scenario 3			Scenario 4			Scenario 5		
		25th perc.	Median	75th perc.	25th perc.	Median	75th perc.	25th perc.	Median	75th perc.	25th perc.	Median	75th perc.
Shared taxi	< 2 km	1	2	2	1	2	2	0	0	0	1	2	2
	[2, 5] km	2	3	4	2	2	3	0	0	0	2	2	3
	[5, 10] km	3	4	6	3	4	6	0	0	0	3	4	6
	>10 km	6	8	11	5	7	9	0	0	0	5	7	9
	Average	4	5	7	3	4	6	0	0	0	3	4	5
Taxi-bus	< 2 km	5	8	12	5	8	12	0	0	0	7	11	17
	[2, 5] km	9	15	21	10	16	21	0	0	0	6	11	16
	[5, 10] km	16	21	26	16	21	26	0	0	0	11	16	22
	>10 km	25	32	39	25	32	41	0	0	0	25	31	37
	Average	12	18	23	14	20	25	0	0	0	9	13	19
Carpooling	< 2 km	7	10	13	6	9	12	6	9	12	7	9	12
	[2, 5] km	6	9	12	6	9	11	6	9	11	6	9	12
	[5, 10] km	6	10	12	6	10	12	6	10	12	6	10	12
	>10 km	7	11	13	7	10	13	7	10	12	7	10	12
	Average	7	10	12	6	10	12	6	9	12	6	10	12

Table 21 displays spatial detours of the shared mobility services under different scenarios. A spatial detour is the ratio of the in-vehicle travel distance by a shared mode to the in-vehicle distance for the same trip performed by private car, along the shortest path. In-vehicle distance by a taxi-bus can be shorter than the corresponding in-vehicle distance by car since the access distance to stops is not included. However, it can also be longer due to the extent of detours. If these two differences are approximately equal, they cancel each other out and the result spatial detour ratio is equal to 1. In the case of shared taxis, it is equal to 1 when the path is identical to that taken by private car and will increase as detour distance increases.

Spatial detour ratios for shared taxis are very low in all scenarios. These results are a consequence of the service design requirements and the high standards set by the model constraints. The obtained values for different distance ranges show that the larger detour ratios happen for distances of less and

two kilometres. This is due to the model design, whereby long trips that reached the maximum-allowed detour time are dispatched to the direct services to meet the model constraints for the desired level of service, hence reducing the detour time to zero.

Table 21. Statistical distribution of spatial detour ratio by travel distance class and scenario

Mode	Travel distance (km)	Scenario 1			Scenario 3			Scenario 4			Scenario 5		
		25th perc.	Median	75th perc.	25th perc.	Median	75th perc.	25th perc.	Median	75th perc.	25th perc.	Median	75th perc.
Shared taxi	< 2 km	1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	1.0	1.0	1.0
	[2, 5] km	1.0	1.0	1.2	1.0	1.0	1.0	0.0	0.0	0.0	1.0	1.0	1.0
	[5, 10] km	1.0	1.0	1.3	1.0	1.0	1.1	0.0	0.0	0.0	1.0	1.0	1.0
	>10 km	1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	1.0	1.0	1.0
	Average	1.0	1.0	1.1	1.0	1.0	1.1	0.0	0.0	0.0	1.0	1.0	1.0
Taxi-bus	< 2 km	1.0	1.3	2.0	1.0	1.3	1.8	0.0	0.0	0.0	1.2	1.8	2.4
	[2, 5] km	1.0	1.1	1.4	1.0	1.0	1.3	0.0	0.0	0.0	1.0	1.2	1.7
	[5, 10] km	1.0	1.0	1.3	1.0	1.0	1.2	0.0	0.0	0.0	1.0	1.1	1.3
	>10 km	1.0	1.0	1.1	1.0	1.0	1.1	0.0	0.0	0.0	1.0	1.0	1.1
	Average	1.0	1.1	1.5	1.0	1.1	1.3	0.0	0.0	0.0	1.0	1.3	1.7
Carpooling	< 2 km	1.0	2.8	3.6	1.8	2.4	3.1	1.8	2.4	3.1	1.9	2.5	3.2
	[2, 5] km	1.0	1.1	1.6	1.0	1.0	1.3	1.0	1.0	1.3	1.0	1.1	1.4
	[5, 10] km	1.0	1.1	1.2	1.0	1.0	1.1	1.0	1.0	1.1	1.0	1.0	1.1
	>10 km	1.0	1.0	1.1	1.0	1.0	1.1	1.0	1.0	1.1	1.0	1.0	1.1
	Average	1.0	1.1	1.3	1.0	1.0	1.2	1.0	1.0	1.2	1.0	1.1	1.2

The taxi-bus mode also achieves good spatial performance, which is stable across all the scenarios. The obtained values indicate a 10-30% increase in the travel distance over direct and shortest-path trips. Carpooling performance is very poor for very short trips but significant in the overall number. In average, 75% of the cases have a spatial detour of less than 30%.

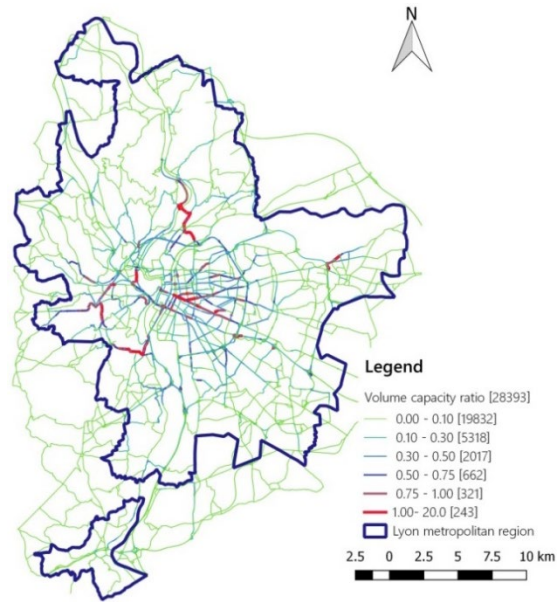
The values of the quality of service indicators in this subsection are smaller for the scenarios with larger adoption rates of shared mobility. This reinforces the importance of the market scale in ensuring high-quality service at affordable prices.

Congestion

This subsection analyses congestion levels at the individual road network links. Comparing congestion levels for the four scenarios to those of the baseline (figures 30-34) shows that congestion levels reduce for most of the links in all four scenarios. There is a sharp decrease in congestion in the central part of the LMR in the full replacement scenario (Sc. 1) and in the LEZ scenario (Sc. 5). Some of the congested sections of the main arteries that access the city centre may be worsened by the additional traffic to access the park-and-ride stations at the LEZ border. The traffic increases on a few sections, which are mainly used to

access shared mobility depot stations or park-and-ride stations (with or without heavy public transport stops). These capacity constraints should be mitigated with a proper local circulation plan for the areas near the depots, and by providing several access points between the depots and the road network.

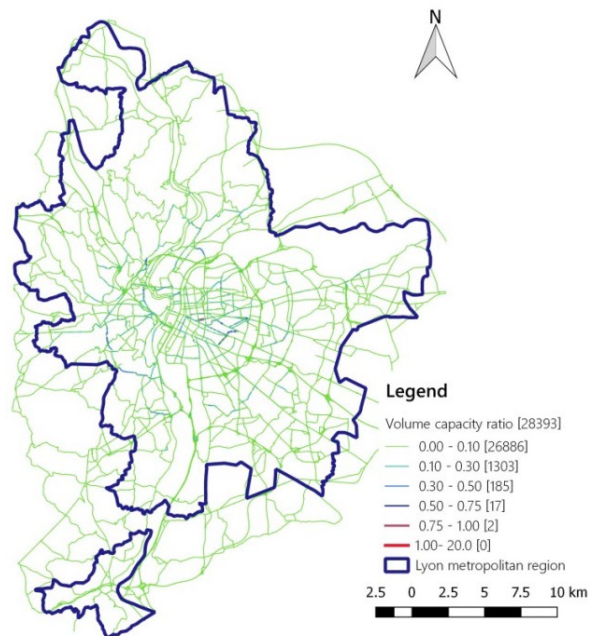
Figure 30. Congestion for each road network link (evening peak) – baseline



Note: Figure 30 is a reproduction of Figure 14 on page 32. It has been included here for easy comparison with figures 31-34.

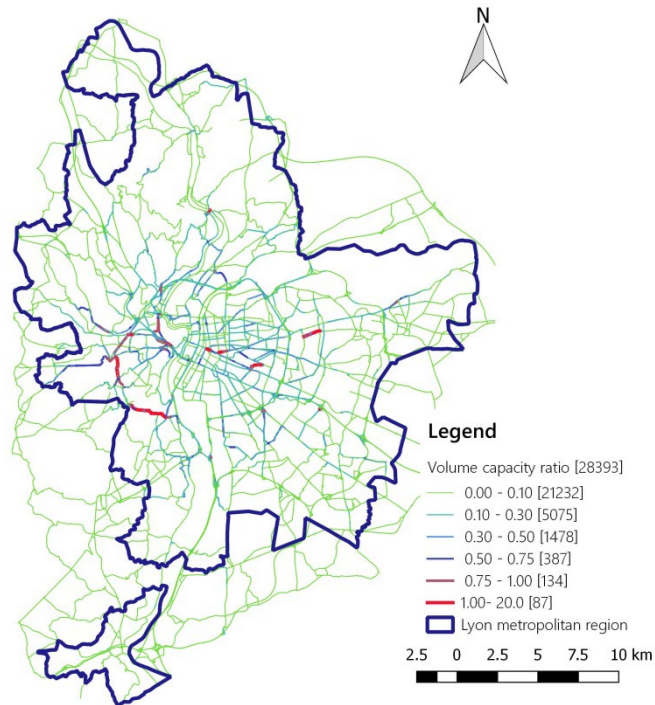
Source: ITF, map tiles by QGIS.

Figure 31. Congestion per link (evening peak) – Scenario 1



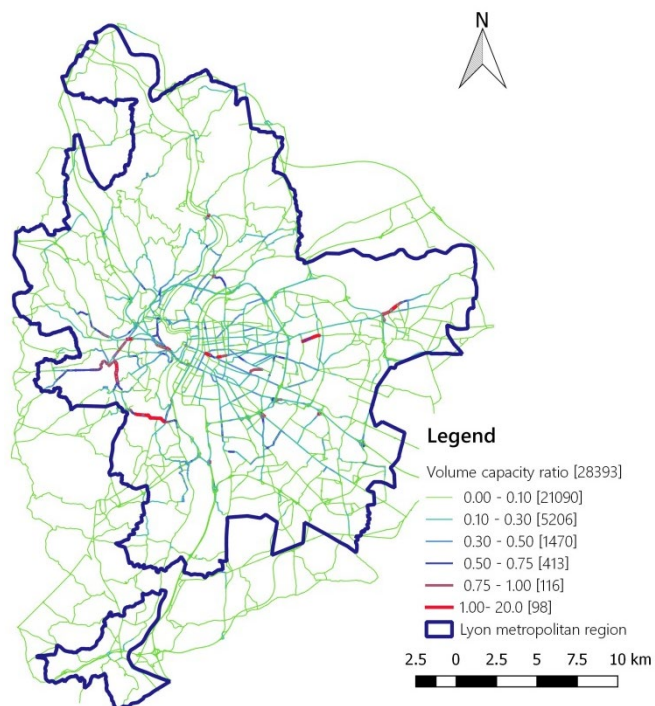
Source: ITF, map tiles by QGIS.

Figure 32. Congestion per link (evening peak) – Scenario 3



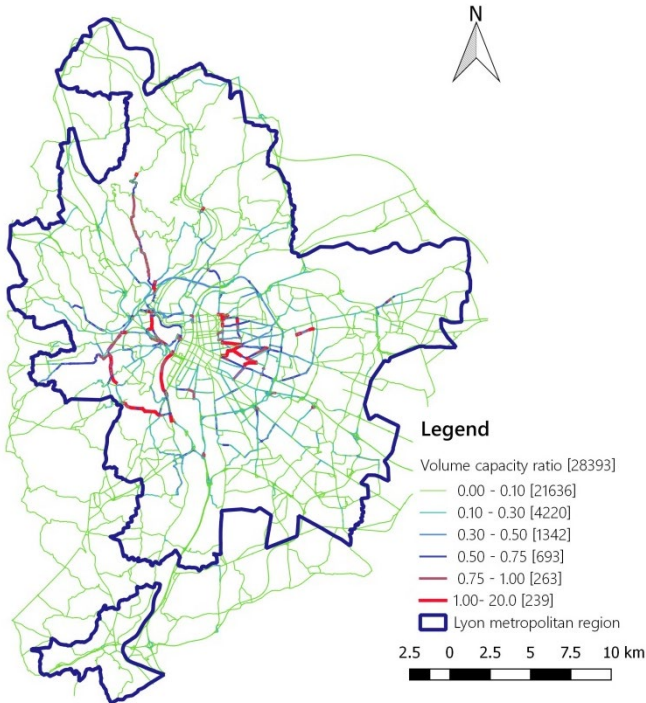
Source: ITF, map tiles by QGIS.

Figure 33. Congestion per link (evening peak) – Scenario 4



Source: ITF, map tiles by QGIS.

Figure 34. Congestion per link (evening peak) – Scenario 5

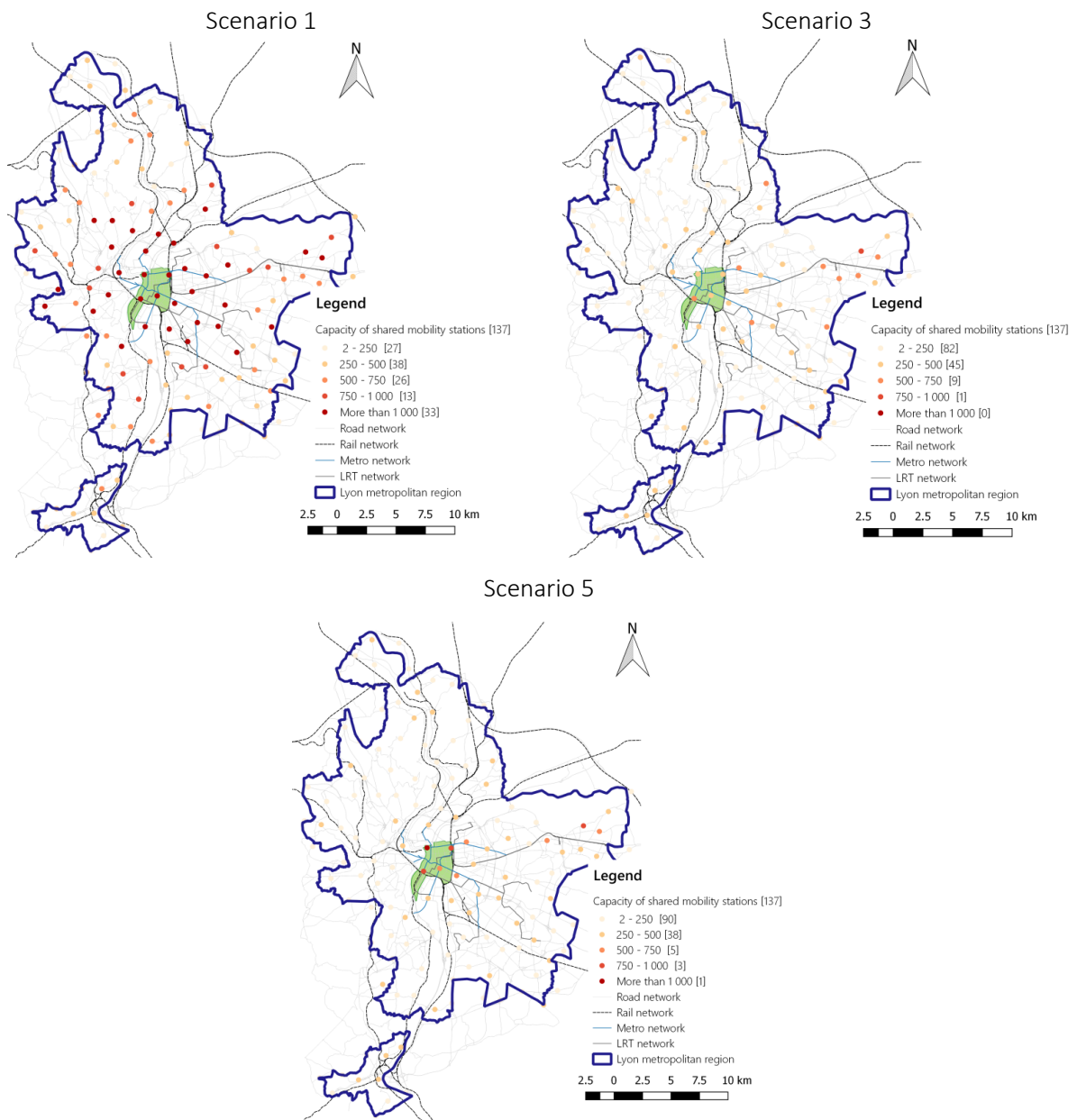


Source: ITF, map tiles by QGIS.

Parking requirements

Introduction of shared mobility on a large scale requires depots for empty vehicles waiting for assignment and for the vehicles of carpooling passengers. Additionally, in the case of the LEZ scenario (Sc. 5), park-and-ride leads to the concentration of vehicles at the LEZ borders, therefore requiring additional parking around the border. This subsection sheds light on the capacity requirements for shared mobility depots and parking stations. As expected, the scenarios with higher rates of adoption of the shared modes require much higher capacity rates at depots (Figure 35). Depot capacity requirements are lowest in scenario 5, with large depots concentrated within the LEZ boundaries.

Figure 35. Distribution of depot stations in the LMR study area



Source: ITF, map tiles by QGIS.

Table 22 presents the number of arrivals and departures at each park-and-ride station and the corresponding requirements for parking capacity. Figure 36 shows the LEZ boundaries and park-and-ride station locations. Most of the park-and-ride stations have a connection with the heavy public transport services, reducing the need for shared mobility feeder services.

Table 22. Flow and capacity requirements for park-and-ride stations in scenario 5

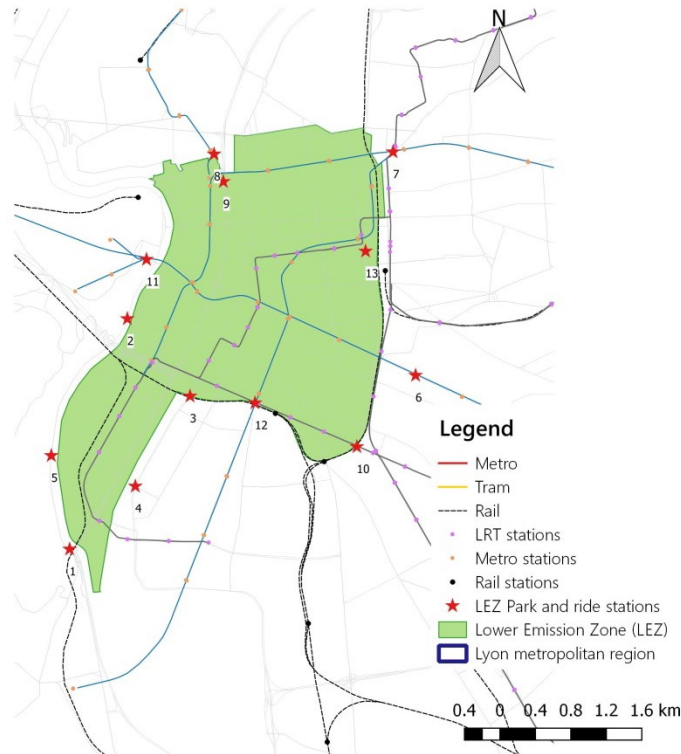
Park and ride stations	Arrivals			Departures			Required parking capacity		
	Car	Taxi-bus	Shared taxi	Car	Taxi-bus	Shared taxi	Cars	Taxi-buses	Shared taxis
1 *	825	1 793	0	2 078	478	0	520	4	0
2	3 564	2 709	1 473	3 951	2 510	1 315	988	21	22
3 *	3 422	2 727	0	3 052	3 012	0	763	26	0
4	1 758	1 589	8	1 919	1 430	4	480	12	0
5	1 782	1 225	221	1 620	1 284	257	405	11	4
6 *	10 414	6 671	197	9 601	7 573	5	2 401	64	0
7 *	6 461	5 030	40	7 238	5 619	34	1 810	47	1
8 *	5 650	3 092	95	4 713	3 587	540	1 179	30	9
9	4 985	2 520	1 491	3 899	3 809	1 530	975	32	26
10 *	4 471	4 550	2	5 365	3 764	0	1 342	32	0
11 *	7 214	6 486	0	8 662	5 249	12	2 166	44	0
12 *	5 038	4 536	2	5 882	3 994	463	1 471	34	8
13 *	8 774	8 241	2	11 334	5 966	384	2 834	50	6

Note: The symbol * represents park-and-ride stations with integration with rail, metro or LRT stations.

If scenario 5 were to be adopted, the flow at the city's LEZ entry points would be significant and the strong transition from private vehicles to public transport or shared mobility modes would generate congestion near the park-and-ride stations. Some stations would receive more than 10 000 arrivals and could require approximately 2 500 parking spaces to accommodate vehicles from drivers towards the city centre. These customers would then transfer either to public transport or to shared mobility. Taxi-buses would be the principal provider of such services at most stations. The busiest stations may require 64 parking stands for people to transfer and 26 shared taxi stands or pick-up and drop-off locations.

These large numbers show the amplitude of the impact such operational measures could have on reducing CO₂ emissions.

Figure 36. Park and ride stations for scenario 5



Source: ITF, map tiles by QGIS.

Operational performance throughout the day

Mobilising fleets for the scenarios with higher shared mobility adoption rates may be challenging for operators. Analysis of the fleet requirement, dynamics and efficiency were undertaken for each of the four scenarios to determine the fleet required to provide sufficient shared mobility supply. Carpooling was analysed separately from the other shared modes due to its unique characteristics.

The scenarios produce stable vehicle occupancy and use rates, as driven by the service design (figures 37-39). Occupancy drops during the night hours only, while the vehicle-use increases at peak times, especially in the afternoon after 17:00. The large drop in taxi-bus occupancy levels at night is caused by client upgrades to shared taxi services since taxi-bus services are unable to satisfy demand at that time. The required number of vehicles is the lowest in scenario 5, with a city-centre LEZ, but similar for the 20% car trips replacement rate in scenario 3. These scenarios, with less shared mobility use, produce a greater drop in off-peak vehicle use, wider fluctuations in vehicle occupancy rates during the day, and system efficiency that is slightly lower than in the full adoption scenario. In scenario 3, which does not include a low emission zone, the required fleet size for shared taxis is larger than that of taxi-buses, as demand is more spacially scattered. Scenario 5, on the contrary, has a higher density of shared mobility trips within the LEZ boundaries and leads to a greater probability of users being assigned to taxi-buses. The results of the taxi-bus operation in the study area may indicate that the system could be supported by a single 16-passenger minibus, with the lower passenger routes serviced by shared taxi vehicles that would operate along taxi-bus stops instead of providing door-to-door service.

Figure 37. Average occupancy and number of eshared taxis and taxi-buses for scenario 1

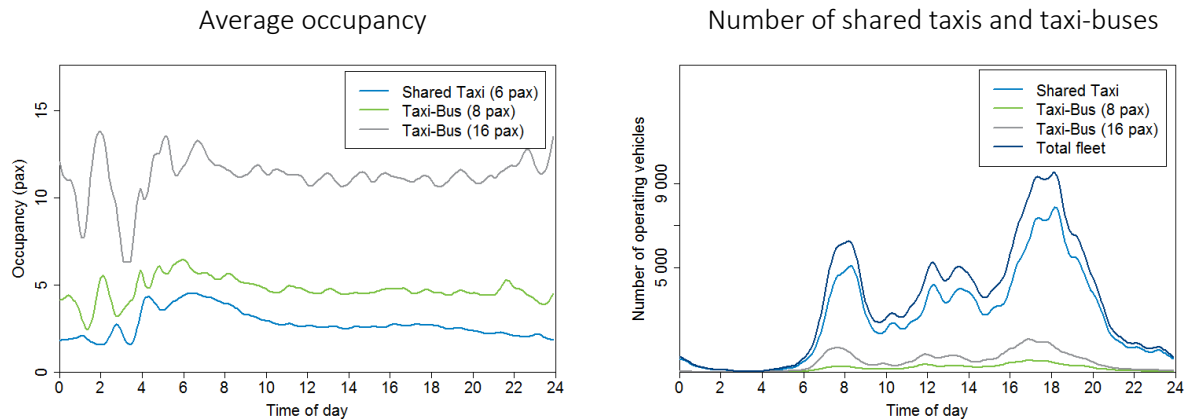


Figure 38. Average occupancy and number of shared taxis and taxi-buses for scenario 3

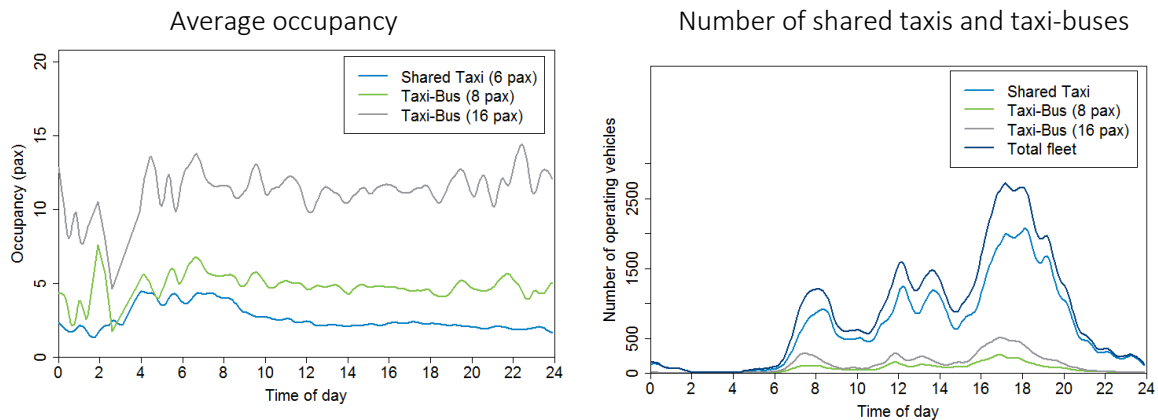
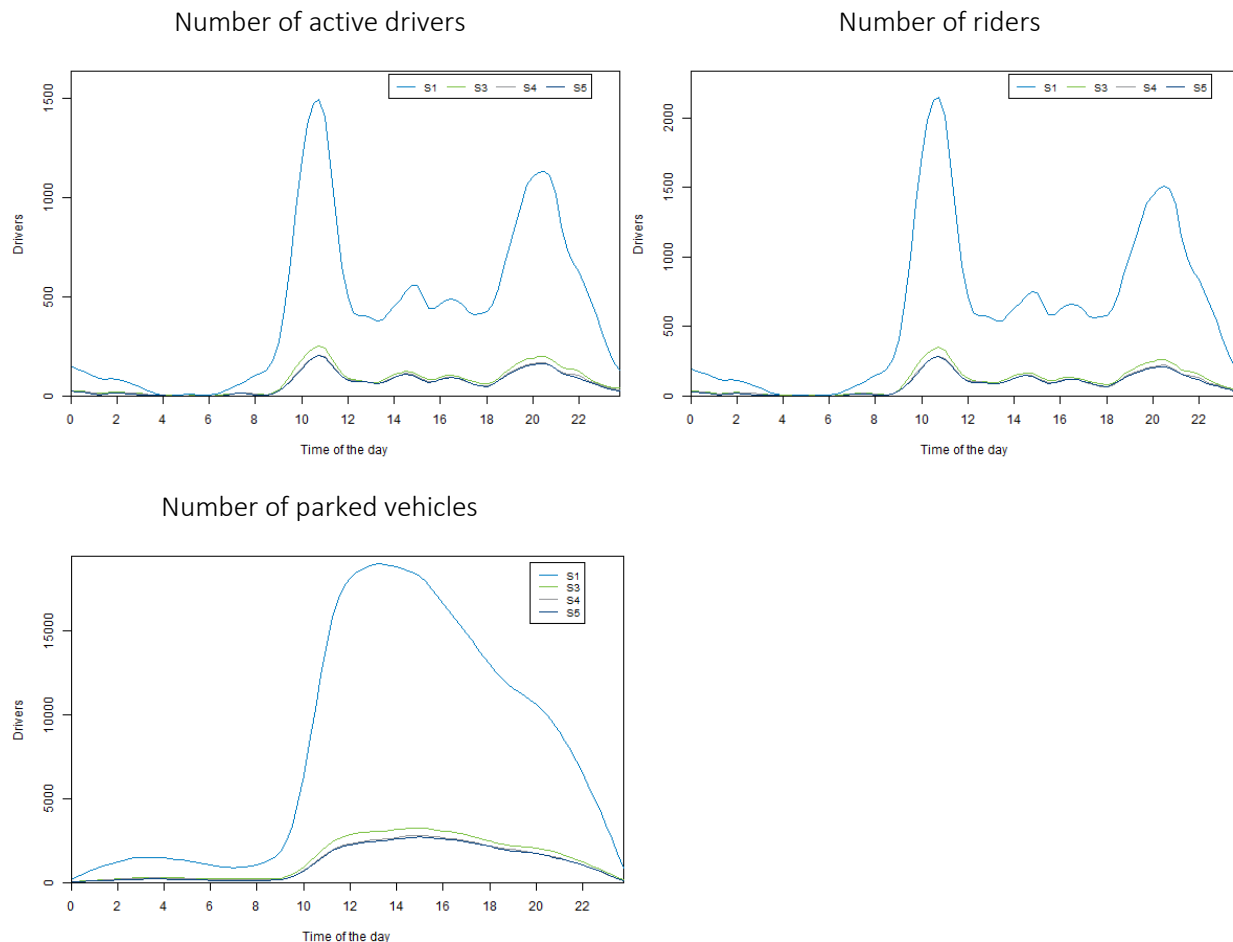


Figure 39 presents carpool performance for scenarios 1, 3, 4 and 5. The results show that in all cases carpools are primarily used to commute to the city centre during peak travel periods, with the most activity during the morning peak. Scenarios 1, 3 and 5 also allow using a different shared mode in the returning trip if a carpooling group cannot be ensured. This flexibility component increases the system's efficiency as well as its ability to persist over time, a principle problem mentioned by Hussain et al. (2016). The party size of carpools is not plotted for different times of the day and different scenarios but is fairly stable around 2.3 and goes up in some scenarios to 2.6 during peak periods.

The parking capacity dynamics is quite stable for different scenarios, filling during the morning peak and reaching maximum occupancy of parking lots between 14:00 and 15:00. Parking usage drops significantly at night. The obtained values show that the parking capacity peak is approximately ten times larger than the maximum number of carpool drivers per 15-minute intervals. The parking ranges from approximately 20 000 cars parked in the full deployment scenario, to less than 3 000 in the localised exclusive carpooling corridors scenario with no other shared modes (Sc. 4), and the LEZ scenario (Sc. 5). Both scenarios require approximately 3 000 parking places. These spaces are located in the designed parking lots inputted to the model in Sc. 4 and at parking lots at the entrance of the LEZ boundary at the park-ride locations in Sc. 5.

Figure 39. Carpooling performance for scenarios 1, 3, 4 and 5



The model also estimates the number of vehicles that are idle at any moment of the day (Figure 40). Generally, an increase in vehicle-kilometres of transportation network companies and taxi services is reported in cities (Rayle et al., 2016). This is because the large amount of idle distances driven by vehicles searching for new clients reduces the benefits for the mobility system in terms of CO₂ emissions and congestion. The ITF model does not allow such movements. Vehicles are always diverted to a depot when idle, minimising idle vehicle-kilometres and the need for road and parking capacity. The idle kilometres performed by drivers increase significantly only at night hours and decrease with the modal share of shared taxis. This fact generates more empty kilometres on average across the day in the LEZ scenario (Sc. 5).

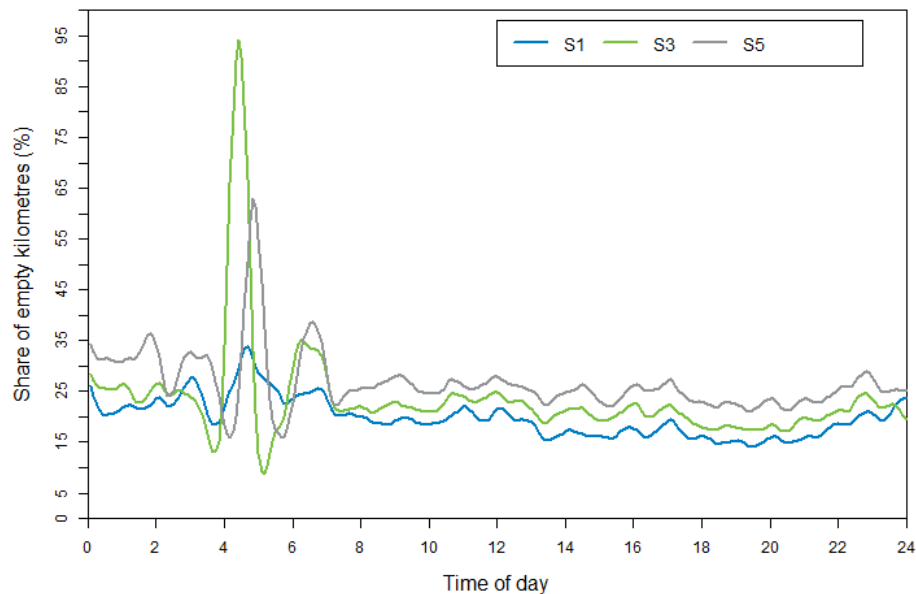
Scenario analysis: Principle take-aways

Shared mobility can substantially reduce congestion and CO₂ emissions in Lyon. Mode shift alone from private cars to shared modes and public transport could result in a sharp reduction in congestion, while a reduction in CO₂ emissions also depends on the spatial distribution of the replaced trips. The scenario with full replacement of car trips shows the best results in both, while carpooling shows interesting potential.

Shared mobility leads to increased levels of accessibility and connectivity, distributing them more evenly across the residents of the area thus providing spatial and social equity. The introduction of shared modes,

and their combination with existing heavy PT modes, substantially increases connectivity by PT, especially for residents who are currently poorly served. At the same time, combining shared services with rail, metro and LRT systems provides former car users with a relatively small increase in overall journey time (due to waiting and detour time) while increasing their flexibility (e.g. freeing users from driving and from maintaining a vehicle for their daily travel).

Figure 40. Share of empty kilometres for shared mobility services in scenarios 1, 3 and 5



Scenario 3, which preserves the conventional core bus network and replaces 20% of the car trips, provides good performance in terms of CO₂ emissions and congestion reduction, outperforming the full replacement of the whole bus network. This fact testifies to the efficiency of Lyon’s current bus network, which provides frequent service along pertinent itineraries. The economies of scale of larger vehicles and the bus fleet are stronger than the additional routing flexibility from a CO₂ perspective. Yet, this scenario would also lead to better connectivity for users.

Shared mobility could potentially increase ridership for rail-based services, especially the number of passengers rather than the pkm. However, all scenarios showed a potential reduction in rail use, as certain lines were replaced by feeder services larger rail arteries where direct trips to the final destination were possible. That said, using shared mobility as a feeder might require investment in infrastructure to increase the capacity of the current rail, metro and LRT systems and their stations. Station layout may need adaption to provide easier access and to ensure sufficient space for vehicles picking up and dropping off passengers. This may be more problematic for LRT and metro stations that are often integrated on the urban tissue.

The results of the operational performance analysis show that the number of required taxi-buses with eight seats is much lower than the number of taxi-buses with 16 seats and shared taxis. This suggests that fewer vehicle types may be required to supply the shared services in the LMR, which might lead to a more optimal allocation of vehicles. During off-peaks, especially at night, there are many idle vehicles, which could be used for other purposes requiring large vehicle fleets, such as urban logistics and deliveries.

Introduction of a small operational area for shared mobility solutions, such as the tested LEZ, reduces the gains for the transport system in terms of CO₂ emissions and congestion and leads to less evenly distributed services across the residents of the different areas. The probability of matching for short trips and for a small number of users is lower, and this reduces the efficiency of the proposed solutions, as observed in the small LEZ scenario. Furthermore, it implies higher shared taxi fares for users. However, this scenario is very beneficial in terms of connectivity indicators. On average, these improve substantially for current PT users and decrease marginally for current car users due to the congestion reduction in the centre of the area. This finding aligns with previous findings for the cities of Auckland and Dublin where the spatially focused LEZ area sometimes produced very concentrated congestion effects at borders.

The test of carpooling as an alternative to traditional car use in Lyon showed some potential. Either the localised tests along the A6 highway corridors or the generalised scenarios produced interesting results with significant CO₂ savings. Although the results are encouraging, private vehicles are still preserved in this system; drivers and riders can remain car-oriented outside the main commuting trips. While other cities provide a similar type of mobility with less than 5% of the current car fleet, the addition of carpooling to the shared mobility MaaS toolset leads to a fleet size of around 13%. This figure more than doubles previous estimates in other shared mobility case studies.

An interesting fact that can be extracted from the results is the gain of the integration of carpooling into a larger set of alternatives, MaaS. One of the main problems with carpooling and ridesharing that is reported in the literature is the long-term stability of mobility (in destination and timing) for all users that increases the drop-off rate of the system over time (Correia and Viegas, 2011).

Key findings and further research

The city of Lyon is characterised by dense urban development, very good public transport and a strong presence of non-motorised modes where walking and cycling represent around 40% of mode share. The results of this study suggest that the success factor identified in previous studies – non-motorised travel share, urban density and public transport provision – are essential if shared mobility is to have a significant impact on the transport system and its citizens. All the tested scenarios lead to considerable reductions in CO₂ emissions and up to a 50% reduction in congestion levels. The gains become more significant when scenarios are implemented across the whole Lyon metropolitan region (LMR) study area, even at lower car replacement rates. In fact, better average connectivity indicators can be achieved in the scenarios with lower levels of car user replacement, due to the reduction in congestion on the one hand, and still high share of trips by private car on the other. For all scenarios, the model also shows increases in accessibility with a more even distribution of the accessibility indicators across the area.

Full replacement of motorised trips in the area could lead to a more than 94% reduction in the total car fleet. Unlike previous ITF shared mobility studies, this report incorporates carpooling as a mode organised by a central dispatcher but not operated or managed by that dispatcher.

The concept of private carpooling or ridesharing has been around for decades and with some degree of success, especially for intercity traffic (e.g. BlaBlaCar). Yet, literature has shown that systematic daily carpooling as a stable commuting solution has proven to be complicated. In this study, a centralised dispatch procedure was incorporated into the toolkit of shared mobility options. The aim was to enlarge the spectrum of solutions for users and to better bridge the gap between private car ownership and shared mobility deployment. Carpooling was incorporated into the mobility toolkit under a paradigm of Mobility as a Service (MaaS) and supported by other public transport options and shared mobility services, which could serve as a replacement service if the carpooling request could not be fulfilled. In the full deployment scenario where carpooling is included, 13% of the fleet is required to provide the same mobility under better equitable performance. Replacing 20% of private car trips with shared modes would still result in an 11% reduction in vehicle-kilometres and a 12% reduction in emissions while the impact on congestion would be even greater (-16%), as carpooling requires less empty or non-productive passenger-kilometres. Carpooling has proven to be a stable means of shared mobility over time, testifying to its durability and to the trust developed between drivers and riders sharing the vehicle (Correia and Viegas, 2011).

The new shared services should be implemented bearing in mind the spatial characteristics of the region, the distribution of the trips and the new public transport infrastructure plans. The integration of the rail and road networks in the regional and national systems should be considered in the design of policies. The results of the taxi-bus operation in the study area may indicate that the system could be supported by a fleet of 8-passenger taxi-buses, foregoing eight-passenger taxi-buses altogether. Less frequented passenger routes could then be serviced by shared taxis that would operate between taxi-bus stops.

The scale of operations of the designed system also opens opportunities to engage the local authorities in partnerships with third parties for procurement, maintenance and operations management, which can potentially provide even more competitive prices for the end users. These partnerships might include new mobility services providers, vehicle manufacturers or even other public transport operators. In addition, fleets of substantial dimension could ensure the necessary economy of scale for massive adoption of emerging technologies such as electric-powered and driverless vehicles.

The study showed that shared modes can be well integrated into the existing PT network. Keeping the core bus network, which covers a significant part of the bus demand, gives positive results in terms of diminishing CO₂ emissions and reducing congestion while maintaining or improving the average level of service for users. Therefore, taxi-bus should cooperate with the existing bus system instead of replacing it.

The feeder services that were tested for the LMR considered the potential interaction of shared mobility with rail-based services (rail, metro and LRT). The results are in line with Lisbon and Helsinki, other cities with good public transport provision where the same model was tested. The main reasons behind this are the spatial coverage of the network, the diversity of services and the good headway of existing services (heavy public transport provision).

Additional system capacity may be required for some stations to accommodate the increased ridership without compromising the current service quality. Some stations' layouts may need to be redesigned to provide sufficient access to users of non-motorised modes and docking areas for shared vehicles to pick up and drop off travellers efficiently and safely. Identifying and redesigning the LRT stations with high potential for shared mobility integration could significantly boost the savings in vkm and CO₂ emissions for the whole LMR.

The results from the stated preference survey indicate that there is a reasonably high interest in using shared mobility services, with a potential of delivering a 20% mode shift from private cars as long as the quality of services is sufficiently high. Still, many users would need to have their private car available, at least in the beginning. The observed familiarity with digital technologies suggests that an app-based system would not constitute barriers to the implementation and use of shared mobility.

The likelihood of achieving positive impacts in the region depends on the ability to attract car users to the new transport solutions. Policy measures, incentives, new services and informative campaigns should be targeted to ensure that potential early adopters and those with long trips are attracted to these services. The stated preference survey showed that the cost of the shared services is the most important attribute that will influence users' mode choice. It also revealed that the average duration of commuting and other common trips, such as trips for shopping and social activities, is between fifteen minutes and half an hour. This is consistent with the average travel times by motorised modes observed in the synthetic population (generated in this study using the 2014 Household Travel Survey and the 2015 Census data), which is a little more than twenty minutes. These findings, in combination with the results of the cost analysis, suggest that using shared taxis will cost less than owning and operating a car for most users.

All tested scenarios show the significant potential of shared mobility services to reduce parking requirements, especially on-street. This may change how curb access is perceived in the city, with the curb's evolution from a parking location to a pick-up and drop-off zone. Lyon's liveability could significantly increase as on-street parking and congestion decrease. However, a massive shift to shared mobility services would require that some of that freed space be transformed into depots for idle vehicles.

The introduction of shared mobility at the scale studied in this report implies changes to travel behaviour and the overall transportation system that are hard to grasp in any single model or study. In addition, fields other than transport will be affected. The simulation provides a very detailed analysis of several scenarios, but it does not take into account changes of the travel behaviour or other disruptions induced by extensive adoption of these services. The introduction of shared mobility can affect land use and real-estate value, for example. The increase in accessibility for currently remote areas can raise their commercial attractiveness and even foster urban sprawl. Estimation of such impacts and the design of policies aimed at sprawl reduction are likely to be required.

Finally, the questions arise of who will provide the new services and in what manner. The necessary level of funding and unprecedented scale of deployment of these services might require a collaborative effort that could involve public transport operators, ride services and taxis, vehicle manufactures and other institutions. The inclusion of carpooling in the shared mobility toolkit would allow for a softer transition from a household-owned car fleet to a more centralised fleet management landscape.

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Annex A. Example of a stated preference survey question

Une enquête d'opinion sur la mobilité partagée LYON shared mobility

2. Préférences déclarées

(2.3.1) Choix du mode de transport *

Ci-dessous, choisissez l'option que vous préféreriez.

Modes de transport non-motorisés

- 1. Temps: **20 mins**
- 2. Existence de trottoires/ de voies cyclables: **Pas de trottoire ou de voie cyclable**
- 3. Mode de transport: **Vélo**

Taxi partagé ou Taxi-Bus

- 1. Temps à bord: **30 mins**
- 2. Prix du ticket: **3 euros**
- 3. Temps perdu (attente et détour pour déposer ou prendre un autre passager): **7 mins**
- 4. Temps de marche (vers ou depuis la station): **5 mins**
- 5. Autres passagers dans le véhicule: **4**

Voiture privée

- 1. Temps de trajet: **15 mins**
- 2. Coût du carburant: **2 euros**
- 3. Coût du parking: **1 euro** /par heure pour une période de 4 heures
- 4. Péage urbain: **Pas de péage**

Transport en commun

- 1. Temps à bord: **40 mins**
- 2. Prix du ticket: **1.5 euros**
- 3. Temps de marche (vers ou depuis la station): **10 mins**
- 4. Temps d'attente: **5 mins**
- 5. Nombre de correspondances: **1**
- 6. Mode de transport: **Train**

Annex B. Characteristics of the two respondent groups

Table B.1. Respondents' distribution by age and residential location (%)

Residential location	Age cohort					
	<=25	26 - 35	36 - 45	46 - 55	56 - 65	>65
Far from the Lyon city centre (>10 km)	0	0	1	8	15	5
Close to the city centre	0	2	12	11	0	5

Figure B1. Respondents' occupation

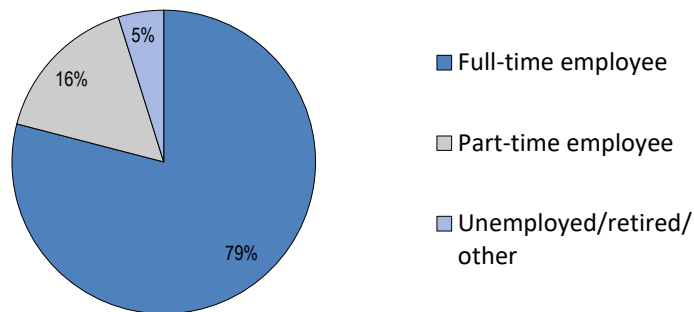


Figure B.2. Number of respondents using smartphones and tablets

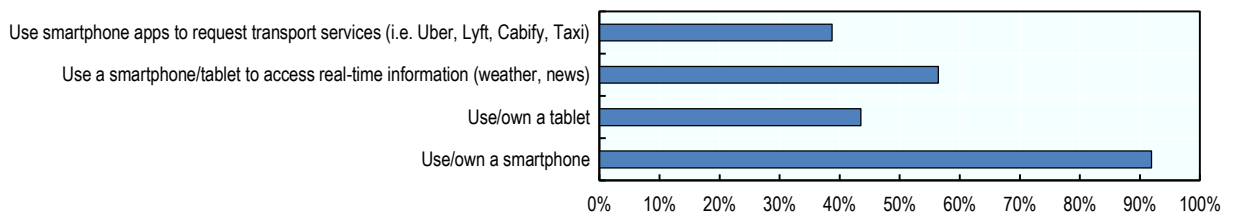


Table B.2. Current mobility patterns of the survey respondents

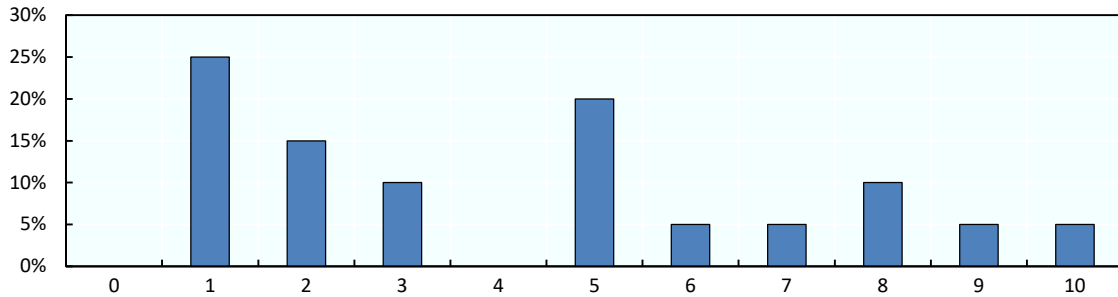
Activity	Average number of weekly trips	Average trip duration (min)	Most commonly used modes
Travel to/from work or place of study	4.9	47	Private car (driver) – 53% Train – 12.5%
Travel to drop off/pick up children at school or childcare, if trip does not include a place of work or study	2.3	20	Private car (driver) – 53% Walking – 27%
Daily shopping (e.g. supermarket)	1.7	13	Private car (driver) – 58% Walking – 27%
Social activity (e.g. visiting friends or family)	1.7	27	Private car (driver) – 60% Metro – 10% Cycling – 10%
Leisure activities (e.g. sports)	1.7	21	Private car (driver) – 35% Cycling – 16% Walking – 16% Metro – 13%
Personal matters (e.g. doctor's appointment)	1.4	16	Private car (driver) – 54% Walking – 19%
Other	0	19	Not possible to identify

Table B.3. Respondents' profiles based on the transport modes they use most (%)

Main transport mode	Age cohort					
	<=25	26 - 35	36 - 45	46 - 55	56 - 65	>65
Car	0	0	4	7	6	3
Bus	0	0	1	1	0	2
Walk	0	0	0	3	1	1
Rail	0	0	5	2	2	0
Other (e.g., cycling)	0	2	3	6	6	4

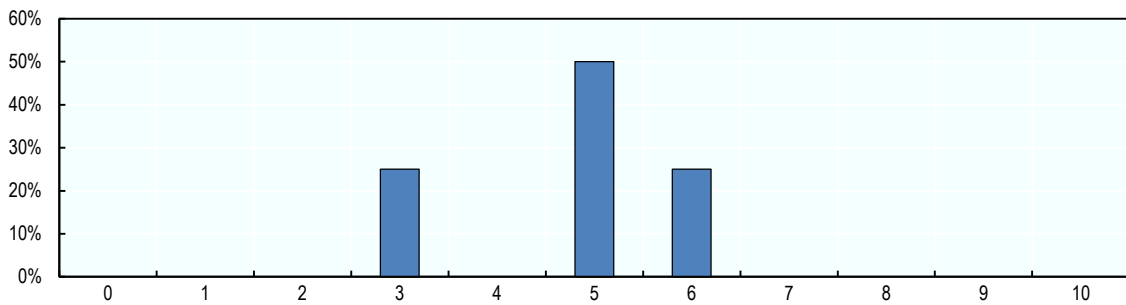
Annex C. Attitudes towards the shared modes and their attributes

Figure C.1. Car users' willingness to pay for shared mobility modes



Note: 0=No response; 1=Not willing to pay for shared modes; 5=Willing to pay half of the current cost of shared mobility modes; 10=Willingness to pay the current value of shared mobility modes.

Figure C.2. Bus and rail users' willingness to pay for shared mobility modes



Note: 0=No response; 1=Not willing to pay for shared modes; 5=Willing to pay the equivalent of the current cost of shared modes; 10=Willing to pay twice the current cost of shared mobility modes.

Figure C.3. Maximum amount of time car users are willing to walk to a shared mobility stop

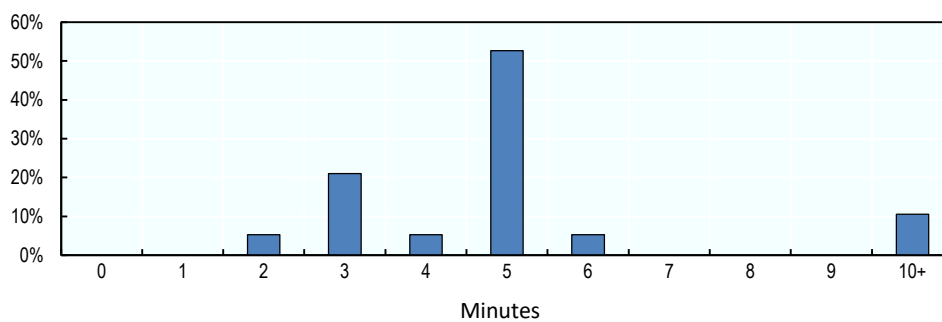


Figure C.4. Maximum amount of time bus and rail users are willing to walk to a shared mobility stop

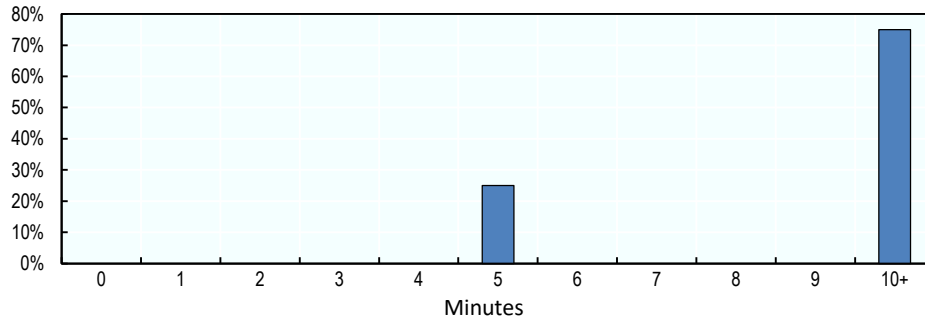


Figure C.5. Willingness to substitute personal car use with shared mobility modes given the additional in-vehicle time

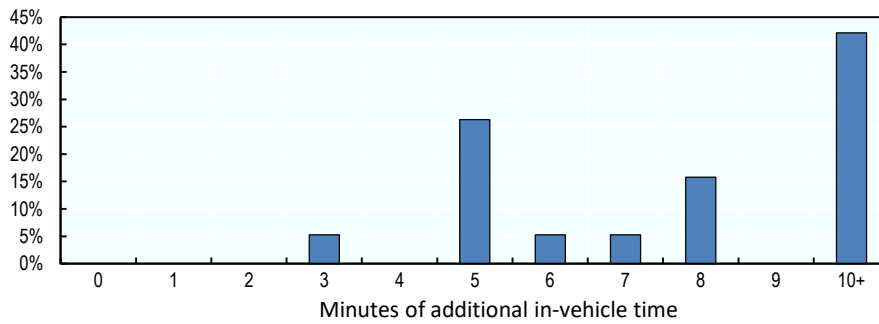


Figure C.6. Amount of additional in-vehicle time bus and rail users are willing to spend in shared mobility modes

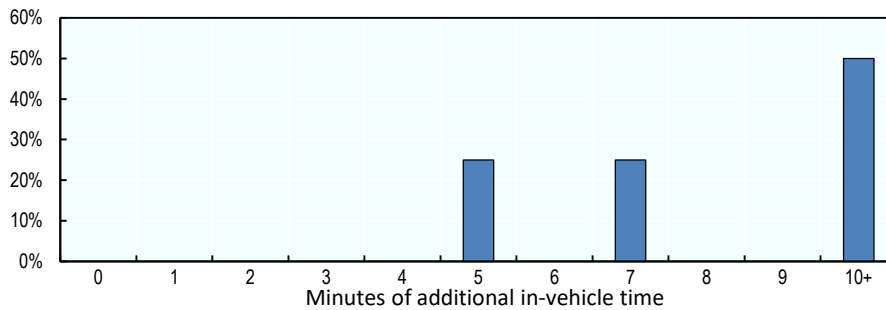


Figure C.7. Relevance for car users of shared mobility modes as a feeder service

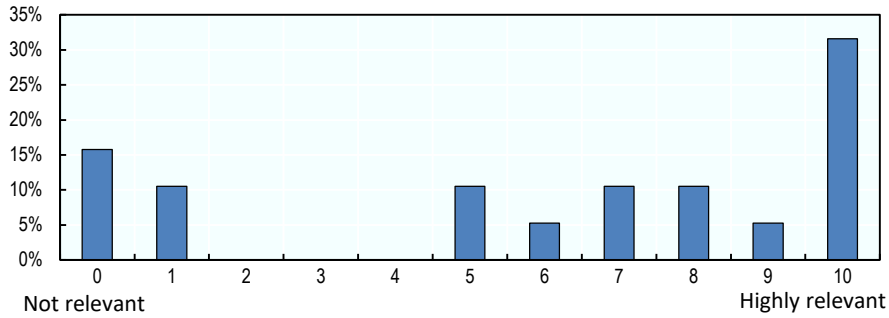


Figure C.8. Relevance for bus and rail users of shared mobility modes as a feeder service

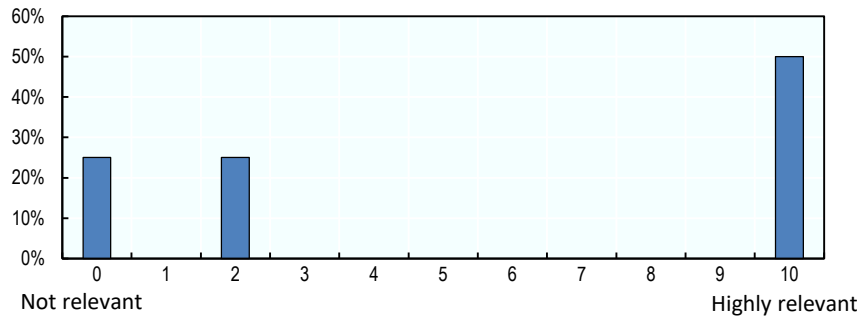
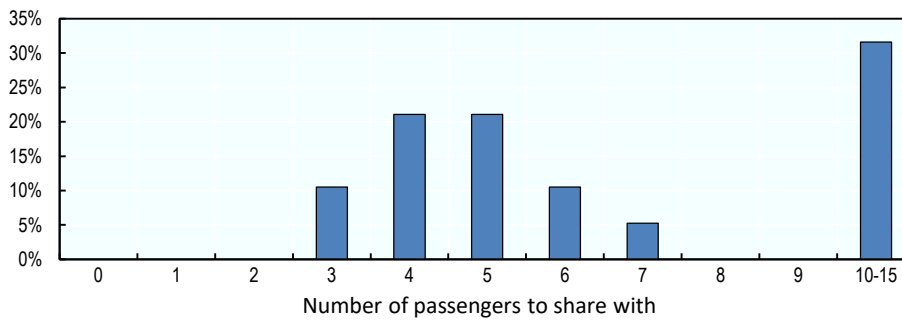


Figure C.9. Number of passengers with whom car users would be willing to share a vehicle



Annex D. Calculation of greenhouse gas emissions

The table below presents the assumptions behind the greenhouse gas (CO₂) emissions calculations for the study. Estimated emissions are based on the CO₂ grams per vkm or pkm data for different modes, provided by local project partners. Emissions for the new shared modes are taken from the Lisbon study (ITF, 2016).

Table D.1. Greenhouse gas emissions of different modes

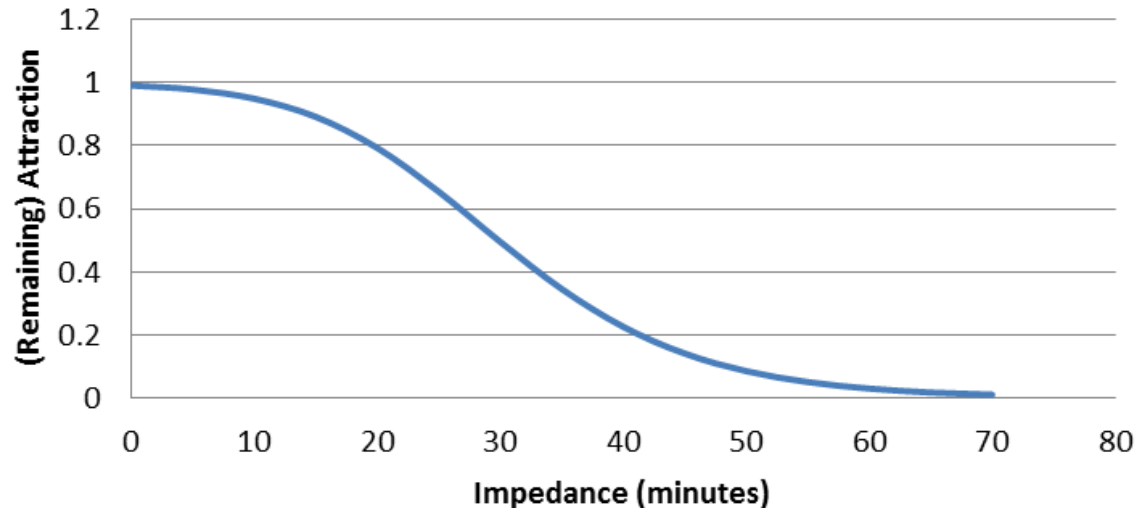
	Value	Unit	Source
Car / carpooling	174.6	g/vkm	Provided by Lyon
Shared taxi	213.4	g/vkm	Lisbon ITF study
Taxi-bus 8	255.3	g/vkm	Lisbon ITF study
Taxi-bus 16	319.1	g/vkm	Lisbon ITF study
Metro	0	g/pkm	Provided by Lyon
Rail	60	g/pkm	Provided by Lyon
LRT (LUAS)	80	g/pkm	Provided by Lyon
Bus	1348.8	g/vkm	Provided by Lyon

Annex E. Effective access

Effective access is a concept that is used across the ITF shared mobility studies (ITF, 2016; ITF, 2017a; ITF, 2017b; ITF, 2017c; ITF, 2018). Accessibility levels are evaluated along a continuum of perception, taking into account not the absolute travel time but the travel time related to a particular origin-destination pair. This provides a better indicator than the absolute travel time since an individual's willingness to go from point *a* to point *b* to carry out an activity usually depends on the remoteness of *b* from *a*. The more the individual needs to travel, the less the destination becomes attractive for carrying out the activity. To account for that, more remote destinations can be penalised by being multiplied by a factor smaller than 1, which decreases as the travel time between the origin and destination increases. An attraction decay curve can calculate the exact value of the penalty. Figure E1 shows that the attraction reduces non-linearly as the impedance (travel time) grows (Martínez and Viegas, 2013).

In order to calculate the effective accessibility to employment, the number of jobs in each destination grid cell is multiplied by the attraction value provided by the attraction decay curve. For instance, if travel time between an origin cell and a destination cell is 40 minutes, the number of jobs existing in the destination cell is multiplied by 0.2 (which is the attraction penalty in the curve for a 40-minute travel distance).

Figure E.1. Attraction decay curve



Source: Martínez and Viegas (2013).

Shared Mobility Simulations for Lyon

This report examines how new shared services could change mobility in Lyon, France. It presents simulations for five different scenarios in which different shared transport options replace privately owned cars in the Lyon metropolitan area. The simulations offer insights on how shared mobility can reduce congestion, lower CO₂ emissions and free public space. The analysis also looks at quality of service, cost and citizens' access to opportunities. The interaction of shared mobility services with mass public transport and optimal operational conditions for the transition are also examined. The findings provide decision makers with evidence to weigh opportunities and challenges created by new shared transport services. The report is part of a series of studies on shared mobility in different urban and metropolitan contexts.