International Transport Forum | CPB Corporate Partnership Board

Transition to Shared Mobility

How large cities can deliver inclusive transport services

Corporate Partnership Board Report

OECD

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Foreword

The work for this report was carried out in the context of a project initiated and funded by the International Transport Forum's Corporate Partnership Board (CPB). CPB projects are designed to enrich policy discussion with a business perspective. They are launched in areas where CPB member companies identify an emerging issue in transport policy or an innovation challenge to the transport system. Led by the ITF, work is carried out in a collaborative fashion in working groups consisting of CPB member companies, external experts and ITF staff.

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Executive summary

What we did

This report examines how cities can manage the challenges of geographical scale and of transition to shared mobility services. It expands on two earlier studies that looked at the impact of replacing private cars in a city with shared services, which did not address the questions of implementation and of expanding these services to a wider metropolitan area. Based again on mobility data for the city of Lisbon, Portugal, this report assesses issues around the scaling up of shared mobility services to the whole of the Metropolitan area and of their stepwise introduction. It also explores how shared mobility can improve accessibility for users with impairments and analyses the impacts of these services on the use of existing high-capacity public transport and on access to jobs across the whole study area.

For this study, different configurations of shared mobility solutions were simulated using advanced computer models that were fed with detailed mobility data for the Lisbon Metropolitan Area (LMA). Specific questions examined were: How do the impacts of shared mobility services on the core city and the wider metropolitan area compare? How could a phased deployment of shared mobility services be organised and what results could be expected for each phase? How would different approaches to organising the dispatcher role influence outcomes? How would a shared mobility system provide equitable access for all in an efficient way and deliver high-quality access also to citizens with disabilities?

What we found

This study found that the reduction of traffic volumes, emissions and also prices as the result of a full-scale implementation of shared mobility in this metropolitan area is even more significant than for the core city itself. For example, total vehicle.kilometres in peak hours are reduced by 55% (compared to 2011) for the metropolitan area, while the reduction for the city alone was 44%. CO_2 emissions are reduced by 62% for the wider agglomeration and 53% for the city.

In wider metropolitan areas, new types of shared services such as Shared Taxis or Taxi-Buses can serve as feeders to existing high-capacity public transport networks such as metro or rail lines. This facilitates the introduction of shared services and increases the use of those high-capacity services and the overall positive impacts in terms of congestion reduction, more equitable access and gains in public space.

Shared mobility makes access to jobs and other public services easier and more equitable. This was already demonstrated for the core city in earlier analyses; this study now finds this is also the case for the larger conurbation. While levels of accessibility differ from area to area, major improvements in access and strong reductions of inequity resulted from the introduction of shared mobility across all of them.

Shared mobility also releases massive amounts of parking space. This study finds that the effect on parking spaces is roughly the same for the city centre and the LMA, with total parking space needed reduced by 95%. The remaining 5% would be primarily used as depots for the Shared Taxis and thus need to be strategically positioned, but the remaining 95% could be reallocated for other public uses.

Regarding implementation, the examination of a phased pathway (starting with potentially uncontroversial measures targeting early adopters) helped to identify a minimum initial push needed to quickly achieve publicly visible results and high levels of satisfaction by the users of the shared services, as a basis for the next implementation phase aiming to achieve the full benefits of shared mobility.

An alternative scenario with differentiated implementation of measures only in the core city but not the surrounding municipalities showed that in the core city implementation of the measures considered for the first phase of the deployment pathway can deliver positive results for the core city when accompanied by a scheme of partial access constraint for private cars of non-residents.

The modelling results also showed that the way dispatch services for shared vehicles are organised strongly affects the overall efficiency of the scheme.

With regard to shared mobility as a tool to improve accessibility for citizens with physical and cognitive disabilities, the simulations for this study indicate a small price increase per passenger.kilometre if the entire fleet of Shared Taxis serving all clients were adapted to accept wheelchairs, compared to a scenario with no service for clients with impairments. However, the resulting price is still much lower than the current equivalent price of regular taxis and even of public transport.

What we recommend

Start to integrate shared mobility solutions into existing urban transport plans

Shared mobility can contribute greatly to achieving key objectives for urban mobility. With today’s technologies, shared mobility can deliver significant improvements quickly and with relatively low risk. In all indicators analysed for this study, the impacts are positive in the city core as well as in the wider metropolitan area.

Leverage shared mobility to increase use of existing high-capacity public transport

High-capacity public transport services offer great value to users, but are often underutilised because of difficulties for users to reach stations in an efficient way. Linking them with demand-responsive Taxi-Buses acting as feeders improves access and increases use. The efficiency of the shared feeder services is also enhanced since they benefit from a common destination for all travellers. In order for the feeder services to operate optimally, the design of the public spaces adjacent to the metro and rail stations must be adapted. Generally, delivering better service through connecting shared mobility solutions with high-capacity public transport requires a holistic approach to planning involving all key stakeholders.

Deploy shared mobility services in a phased way that maximises public acceptance

Phasing in shared mobility should be done in steps that are based on goal-oriented policy measures, delivering at each step sufficient progress on core objectives such as reducing congestion and emissions, so that an easy perception of collective benefits can be associated with a positive experience by those who shift to the shared modes. This alignment facilitates public acceptance and can have a strong influence on adoption rates.

The measures for each implementation phase must focus as much on managing private car use as on providing a high-quality service to those who try the shared mobility solutions.

Because urban characteristics and political environments differ for each city, the feasible deployment scenarios could be very different from those tested in this report. The scenarios described here have far-reaching impacts beyond those linked specifically to transport and mobility. Managing the transition described in this report will therefore require addressing a broader range of considerations and preparations beyond the strict transport-related measures described above.

Optimise overall efficiency while assuring a healthy level of competition in the market.

Market structure scenarios indicate these choices have an impact on efficiency for Shared Taxis and Taxi-Buses. The single dispatcher model resulted in the greatest efficiency gains but the exact relationship between dispatcher and operator may follow different models and these relationships should be carefully assessed in advance. The dispatcher could be organised as a public monopoly or a regulated, time-bound private concession selected through a competitive process. In order to encourage healthy competition in the market, multiple operators of shared services could be accepted and societal gains achieved through their capacity to innovate and differentiate themselves in pursuit of more clients, but routing decisions would remain the purview of the dispatcher.

Limit exclusive occupancy of shared vehicles to avoid the erosion of traffic reduction and CO_2 emissions benefits

Responding to exclusive occupancy requests for Shared Taxis by clients has a natural market and should be possible. However, the price difference to shared use should be calibrated to avoid large-scale exclusive occupancy of vehicles that would considerably hamper the system efficiency both in reducing traffic volumes and CO_2 emissions. In a simulation with a small percentage (4.1%) of trips requesting exclusive occupancy, the loss of reductions of traffic volumes and of CO_2 emissions in relation to the scenario with no exclusive trips was amplified by a factor of 1.7 (i.e. led to 6.9% loss of those reductions).

Leverage the significant potential of improved territorial accessibility created by shared mobility

Shared mobility systems allow large improvements in equitable territorial accessibility. It is imperative that city planners understand the impact of shared mobility on spatial accessibility and make use of its potential to deliver equitable access. Taxi-Bus trips typically only take half the travel time compared to traditional public transport because transfers are not required (except where shared vehicles feed existing metro or rail lines) and smaller vehicles need to stop less often to fill up with passengers. This radically increases range and hence access to the number of jobs and social services, especially for citizens in areas that are poorly served by traditional public transport. City planners need to be aware of this possibility and be part of the dialogue preceding the deployment of shared mobility services.

Make shared mobility services fully accessible to citizens with reduced mobility

Every citizen has a right to good access to personal or professional opportunities and transport services to reach them. For those with impairments and special mobility needs, Shared Taxis that are fully accessible, e.g. for wheelchair-bound clients, would significantly improve the range of reachable opportunities and overall quality of life. Results indicate that this benefit could be achieved with minimal impacts on operating costs.

1. Introduction

The nexus of digitalisation, new business models, ubiquitous computing and platform-based supply/demand matching is already beginning to have an impact on many aspects of modern life, including the way in which people and goods move about cities. Going forward, these trends are likely to lead to a drastically different mobility landscape in cities – one that has the promise, but not the certainty, of delivering better access, traffic and environmental outcomes than what is possible today. But there is also much uncertainty about how technology and business models may evolve and under what configuration mobility services will be delivered in cities of the future. This uncertainty rests not just on drivetrain technologies and fuels, but on the future evolution of public transport and on where the balance between individual and shared mobility may finally settle. The future of mobility in cities is likely to be driven partly by technological innovation from the private sector and by the framework and guidance put in place by authorities responsible for regulating public space, transport services and delivering better outcomes for all citizens. It is in that context – of helping authorities understand and possibly guide future developments – that the ITF through its Corporate Partnership Board, has engaged in detailed modelling of what innovative mobility services built on optimised sharing of transport assets may bring to future cities.

This work has resulted in two reports – *Urban Mobility System Upgrade: How shared self-driving cars could change city traffic* (ITF, 2015) and *Shared Mobility: Innovation for liveable cities* (ITF, 2016a) that have demonstrated the potential for optimised, shared mobility systems to deliver much more efficient transport services, reduced congestion and lower environmental impacts while delivering better spatial accessibility and being generally cost-competitive with current options. This work has investigated replacing all car- and bus-based trips in a mid-sized European city (Lisbon) with two new mobility options: on-demand, door-to-door and dynamically dispatched Shared Taxi services, in which up to six people get in and out of a roomy vehicle along trajectories that are optimised in real-time; and a street corner-to-street corner Taxi-Bus service that requires 30-minutes advanced reservation and that provides transfer-less trips using minibuses along dynamically defined routes. Other trips are carried out by high-capacity public transport or by walking or cycling. The analysis consists of running an agent-based simulation allocating the entire synthetic trip population which plausibly represents the actual number and characteristics of all trips taken within the city on a normal week day to one of the travel options outlined above with constraints on minimal detour distances and times.

The results of the modelling exercise are unequivocal – the shared mobility system, as configured and modelled for the centre of the Lisbon Metropolitan Area (LMA), delivers much better outcomes than today's transport system. However, the outcome of this work should not be seen as an accurate prediction of what the future will bring to that (or other) cities or as a definitive indication of the potential for shared mobility. It is a detailed and robust "what if" exercise that highlights the order of magnitude and scope of changes that might result from the full deployment of shared mobility systems in cities. One reason the results are only an indicative predictor of the future is because the model does not include iterative feedback loops that would otherwise capture changes in behaviour induced by the types of changes described in the scenarios. For example, if transport costs were to reduce dramatically as suggested by the simulation model – including the reduction of the generalised cost of transport implied by a congestion-less future – people could make different choices regarding home and work locations and develop alternative (possibly longer) travel patterns than those they have today.

Another reason that these "all-in" scenarios say little about the final potential for such shared use mobility systems is that it isn't clear how these systems might operate in different geographic contexts, urban scales or during the transition to whatever the final penetration level for these services amongst the overall transport offer might finally settle. It also isn't clear if these systems can meet the mobility needs of those with physical or cognitive impairments at least as well or better than what is possible today. These are important questions that the present report (and other related work at the ITF) tackles.

In terms of testing the results of initial shared use model runs for Lisbon in other geographic contexts of identical scale, the ITF has initiated similar modelling of shared use systems in three other medium-sized cities (so far Auckland, Dublin and Helsinki) with an eye to testing the model in geographically, culturally and morphologically distinct cities around the world.

In addition to the elements outlined above, this report looks at:

- What are the impacts of urban scale compared to the initial findings of the modelling exercise undertaken in previous reports for the central Lisbon Municipality? How does the performance of optimised shared mobility services change when the larger Lisbon Metropolitan Area as a whole is considered and not just the urban core.
- What might be the impact of graduated deployment of these services along a plausible early adopter pathway?
- What is the impact of different market structure configurations on the efficiency of shared use mobility systems?
- Can shared optimised mobility services deliver high-quality accessibility to those with reduced mobility and cognitive difficulties and, if so, under what configuration?

2. Scaling up: Evolving from city to regional level

Description of the modelling framework

The agent–based model

This report and previous work is based on an agent-based model that simulates the daily mobility of various cities – in this case the city of Lisbon in Portugal. The model is built around three main agents that interact in a common environment: users, vehicles and the dispatching entity. The model works with a synthetic population of trips that serves as a plausible proxy for every trip taken on a normal weekday. These trips occur across a spatial context where transport networks are present (for road, rail and ferries) and where public transport supply is represented by existing routes (bus, metro, rail, and ferry services across the river). The model addresses the interaction between clients and vehicles, simulating their connection and how, in terms of timing and location, the services are performed. The approach is based on a static representation of the traffic environment where origin-destination flows are allocated to a rather complete, topologically correct road network that accounts for per-link occupancy (and thus for speeds), by time of day. Travel time is attributed to each arc and intersection using a dynamic traffic assignment procedure that updates travel time estimates based on flow capacity ratio every five simulation minutes.

In the simulation for shared use services, the dispatcher system manages the centralised task of assigning trip requests to vehicles using the location of shared vehicles, their current occupancy level and the location of clients as its main inputs. The model estimates trip routing on the basis of an algorithm that generates the lowest time cost and insertion cost path between any pair of nodes of the network.

The city centre is divided into a homogeneous grid of 200 metre (m) x 200m cells, whereas the greater Lisbon Metropolitan Area is segmented into a grid of 500m x 500m cells. All trip origins and destinations are linked to the closest node of the road network.

Modelled shared use options

Two shared use modes serve as the basis for the shared mobility modelling exercise: a ride-sharing system (Shared Taxi), which emulates a taxi-like system where customers accept small detours from their original direct path and share part of their ride with others, and a dynamic bus-like service with minibuses (Taxi-Bus), where customers pre-book their service at least 30 minutes in advance (permanent bookings for regular trips could represent most requests) and walk short distances to a designated stop. In all cases travellers get a transfer-free trip from origin to destination. Table 1 presents a brief characterisation of these two modes.

Table 1. **Specifications adopted for the shared mobility services**

Mode	Booking	Access time	Max. wait time	Max. total time loss	Vehicle type
Shared Taxi	Real time	Door-to-door	5 minutes (for a trip ≤ 3 km), up to 10 minutes (for a trip ≥ 12 km)	(detour time + waiting time) from 7 minutes (for a trip ≤ 3 km), up to 15 minutes (for a trip ≥12 km)	Minivan currently seating 8 rearranged to seat only 6, providing easy entry and exit
Taxi-Bus	30 minutes in advance	Boarding and alighting up to 300m away from door, at points designated in real time (street corner-to-street corner)	Tolerance of 10 minutes from preferred boarding time	Set by the minimum linear speed from origin to destination (15 km/h)	Minibuses with 8 or 16 seats. All passengers seated - no standing

The specifications for these services were designed for a high level of acceptance of modal transfer by current car drivers, by providing them with the three quality attributes of flexibility, comfort and availability. The Shared Taxi and Taxi-Bus services were designed to fully replace current motorised road transport alternatives (car, motorcycle, taxi and bus), implying a modal shift of users to the new transport alternatives or to the previous options that remain available (walking/cycling, metro, rail and ferry).

Demand and mode choice

Based on an extensive mobility survey conducted in Lisbon Metropolitan Area (LMA) (Câmara Municipal de Lisboa, 2005) the model input is a synthetic population of people and their trips that contains logs of every single trip disaggregated at the census block level and in time (e.g. recording different trip departure and arrival times) for a normal week day in the reference year of 2011.[1]

Each trip is characterised not only by its time of occurrence, origin and destination, but also by trip purpose, composition of the trip party in terms of age and by whether or not its members have a public transport pass or not. Additionally, based on census data and other mobility surveys, each trip party member is further characterised by the traveller's gender, income and by whether or not the traveller has a driving license, car, motorcycle, parking spaces at home and at work. The purpose of the trip determines the activity duration, which can be used to calculate parking costs.

The destination grids are characterised by parking cost and parking pressure (ratio of demand to supply), both depending on time of day, linking the available demand data with the statistics and pricing of Lisbon's parking.

For all modes currently available – car, motorcycle, taxi, walking, bus or tram, cycling, metro or suburban train, and ferry, combination between low and high capacity transport modes – the trip is characterised by access time, waiting time, travel time, cost and number of transfers (if applicable).

A procedure for modal choice, similar to that adopted in the earlier Corporate Partnership Board (CPB) studies, was adapted to the LMA case, as described below. When the model chooses a shared option, a new user (agent) is generated in the simulation environment, with a departure node, an arrival node and a starting time. Currently, one user is equivalent to one trip, i.e. users do not cluster in parties at the outset of their trip (though they do share vehicles whilst underway in the Shared Taxi and Taxi-Bus simulations).

Users

In the simulation environment, a trip is generated when a user (or party of users) requests a service from one point towards another point. The model accounts for the simulation parameters (resulting from the specification of each shared mode) and accounts for waiting time, detour time and arrival time tolerances that are defined for the model run. The dispatcher then finds, in real time or with the pre-booking, the best possible routing and assigns one of several available vehicle types to carry out the trip in a shared mobility solution.

The user then waits for the vehicle (Shared Taxi) or walks to a specified pick-up location (Taxi-Bus) and boards the vehicle. When the vehicle arrives at its destination, the user exits the system and a set of indicators are generated in a trip log so that they can be used for ex-post system evaluation.

Cars and minibuses

Idle cars are located in stations (depots) spread across the city and whenever the car is empty and not dispatched to a new trip, it returns to the nearest station. Active cars follow the shortest path and minimise travel time for its route assignment taking into dynamically updated link travel times and intersection delays (every five minutes).

Taxi-Buses are located at the departure stop on each generated route by relocation from the last performed service. The location of all these "pop-up" stops was defined at the outset, constrained by minimum distance between stops (300m) 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 streets with traffic only in one direction or left-turning blocking).

The fleet of cars and minibuses is an output of the simulation by measuring the number of vehicles that are required for the simulation and their relocation dynamics between stations during the day. The minibuses required are differentiated between 8- or 16-seated passenger minibuses, and are allocated according to demand.

The dispatcher

The dispatcher acts according to a set of rules for matching cars to users, centralising all real-time information required to produce and monitor these trips. The choice of which Shared Taxi or Taxi-Bus to match with a user's request takes into account a time-minimisation principle that applies not just to the requesting user but also to those already underway in the same vehicle.

Several parametric constraints have been defined that must be satisfied for each trip route solution proposed by the dispatching system as described in the service specification section.

The model defines in parallel the dispatching of Taxi-Buses and Shared Taxis when both systems are operating. Users launch their requests; their preferences are already pre-recorded in the system. Taxi-Bus requests are processed 30 minutes in advance. Shared Taxis are processed in real time. The dispatcher runs a local search algorithm that tries to maximise the number of passengers assigned complying with the users constraints at each step (best match in Taxi-Bus service that warrant at least 50% occupancy (at least for some part of the trip) and an average distance based occupancy rate greater than 25% of the vehicle capacity). The users who are not assigned to Taxi-Buses because of these constraints are then re-assigned (upgraded) to the Shared Taxi system as real-time requests, following the Shared Taxi real-time booking system automatically performing door-to-door services. This upgrade option was enacted since it could provide higher quality for the user at a lower supply cost.

The dispatcher also controls the vehicle movements when idle, ensuring efficient vehicle movements to stations that may require additional fleet in the near future.

Scaling up to the greater Lisbon Metropolitan Area

The previous two CPB studies (ITF, 2015; 2016a) modelled shared mobility systems for the municipal area of Lisbon (referred to as the "city" in this study) – the central core of the greater Lisbon Metropolitan Area (LMA). It wasn't clear, however, whether the findings would hold at a much larger scale – in this context, for the whole of the LMA. In order to test the model and impacts of shared mobility services at this scale, a number of significant adaptations to the model were required. These adaptations include changes and improvements in the inputs, adaptations in the methods to deal with the change of scale, and the diversification of the shared services provided and their integration with metro- and rail-based public transport services.

The LMA has approximately 2.8 million inhabitants, representing roughly 25% of the Portuguese population, with an area of about 3 000 km^2 formed by other 18 municipalities (officially just 17 as Azambuja is not considered part of the region). Figures 1, 2 and 3 show the extent of the LMA as compared to the city of Lisbon proper, as well as the population and employment densities for the region.

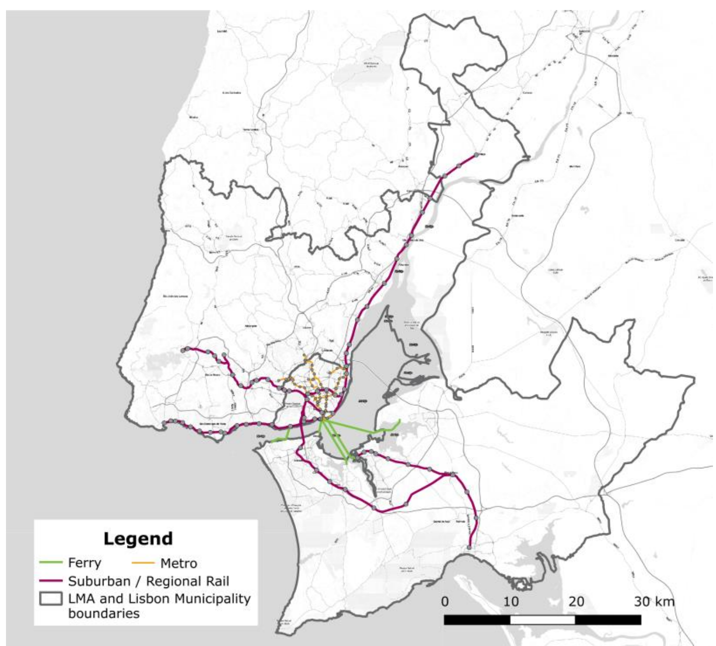
The LMA generates 5.03 million person-trips each day, corresponding to 4.64 million trip parties. The difference corresponds to trips of parents with their children or to accompanied seniors, only counted as one trip in the model (but with the correct party size). Of this total activity in the LMA, about 1.1 million trips take place within the administrative boundaries of the city.

Table 2. **Comparison of Lisbon City and Lisbon Metropolitan Area**

Indicator	Lisbon City	Lisbon Metropolitan Area (LMA)
Area	84.6 km^2	2,957.4 km^2 (x35)
Population	547 733	2.8 million (x5)
Trips	1.1 million	4.6 million (x4.2)

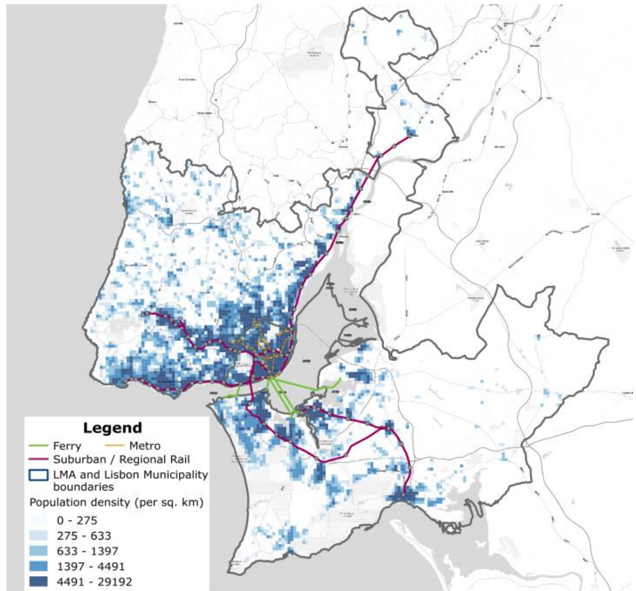
As in many urban areas, the city of Lisbon has a greater incidence of non-individual car-only based trips (61%) as compared to the part of the LMA outside of the city centre (53%) (see Table 3). Looking at the breakdown of trips by major operational zone in the Lisbon area as compiled from individual corridor-based analysis, car-based mobility is highest for trips going to and from central Lisbon from the outer zones (76% of these trips are by car) as shown in Table 4.

Figure 1. **Extent of Lisbon and Lisbon Metropolitan Area**



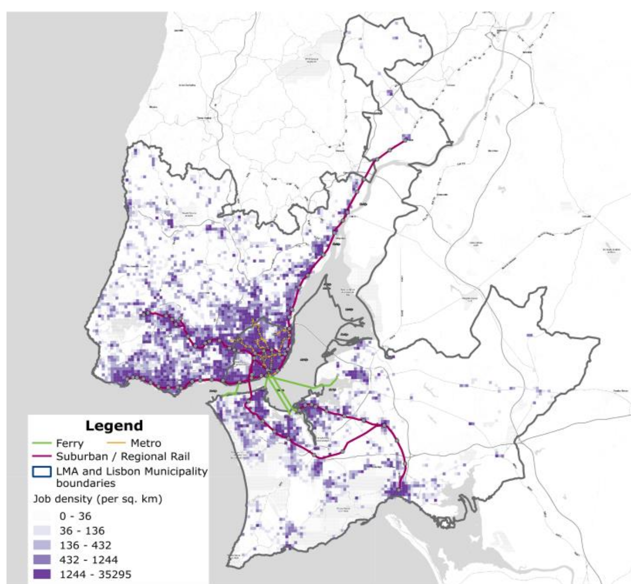
Source: ITF, Map tiles by QGIS.

Figure 2. **Population density for Lisbon Metropolitan Area**



Note: 500m grid, quartile/equal count breaks.
Source: ITF, Map tiles by QGIS.

Figure 3. **Job density for Lisbon Metropolitan Area**



Note: 500m grid, quartile/equal count breaks.
Source: ITF, Map tiles by QGIS.

Table 3. **Transport mode share (Passengers)**

	Current mobility		
	LMA (%)	**Lisbon city (%)**	**Outside of Lisbon city (%)**
Private car (PC)	45.9	39.5	47.8
Motorcycle	1.1	1.0	1.1
Taxi	2.1	1.7	2.1
Bus	20.3	18.3	20.9
Walking	18.5	24.0	17.0
High capacity public transport (rail, metro, ferry)	6.9	12.7	5.3
PC + High capacity modes (rail, metro, ferry)	1.3	1.1	1.4
Bus + High capacity modes (rail, metro, ferry)	3.9	1.8	4.5

Table 4. **Mode share by operation area compiled from corridor-based analysis: Reference case (2011)**

Per corridor			Modal shares (Whole day)								
Operation area	PKM whole day (%)	PKM morning peak (%)	Bus (%)	Metro (%)	Rail (%)	Light Rail (%)	Ferry (%)	Motorcycle (%)	Private car (%)	Walk (%)	Taxi (%)
Internal to Lisbon	9	8	15	10	1	0	0	1	57	12	3
Radial from/ to Lisbon	46	42	8	2	7	0	1	1	76	1	4
Between North Bank Municipalities	31	35	14	1	6	0	0	1	68	6	4
Between South Bank Municipalities	15	15	18	0	2	1	0	1	66	8	4
Total LMA	100	100	12	2	5	0	0	1	70	5	4

Note: PKM = passenger.kilometre

The total daily number of trips considered in this study (all corridors, all modes) is 4 606 330. The morning peak represents 18% of these trips.

Transport challenges and solutions emerging from the change of scale

The expansion of the model from the city to the LMA required several adaptations to the model inputs and simulation model. The most relevant are:

- The development of a new activity-based model that incorporates all information at the household level and the connections between the activities of different households.
- The optimisation model for Taxi-Bus operations had to be adapted to improve calculation speed for the whole LMA. In order to do this the LMA was split into different service areas linked by corridors.
- The mode choice model developed for the city was adapted and expanded to the LMA. This procedure allows estimating the preferred mode under the most extreme configuration of full shared mobility deployment in the LMA. Additionally, through an indicator of early adoption, it sets the order of customers in adopting shared mobility.
- The change of scale required modifying the spatial resolution in the model for the LMA area outside of the city to ensure that the available memory to run the model was sufficient.

- The expansion of the design of shared services for the LMA requires a deeper integration with public transport infrastructure and services. The shared services, especially the Taxi-Bus, are organised to provide feeder services at origin or destination to and from high capacity public transport (rail, ferry and metro stations). These services make more sense at a metropolitan level where the savings on travel time and cost to connect the high efficiency public transport networks can greatly enhance accessibility.

New activity-based model approach

The development of the model for the LMA also required important changes to the way in which synthetic trips were generated. While previously a synthetic trip dataset was created inside the city using a probability specification of each origin-destination (OD) pair along the day, the new LMA model generates information on the household composition, the activity of each individual member and the resulting mobility considering the connection within the household in common activities and use of the household private vehicles.

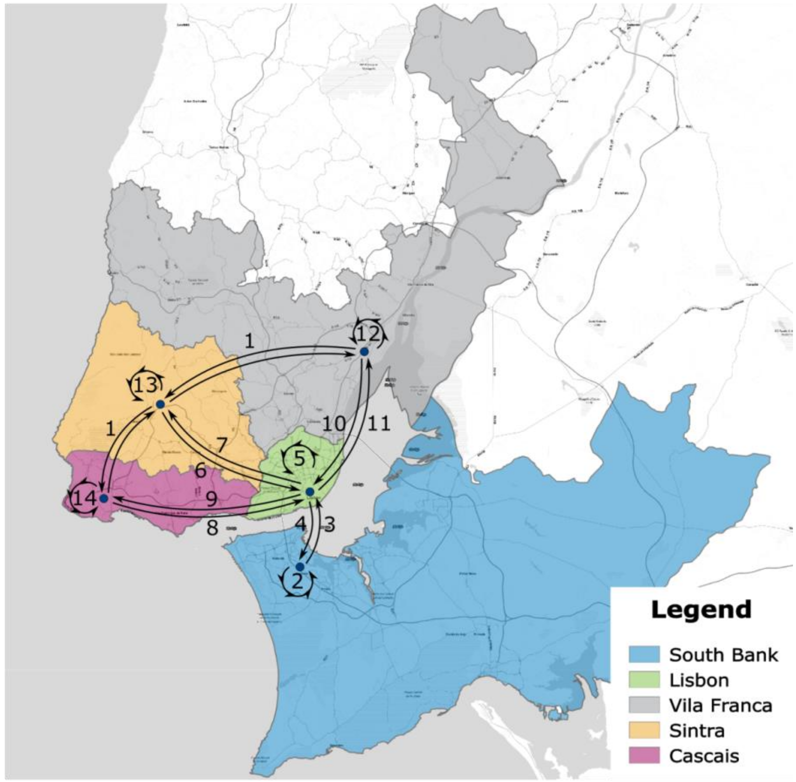
The current model encompasses an activity-based model that has three main components: the development of a synthetic population (calibrated to match the 2011 Portuguese Census), the creation of the structural activity for all household members over 13-years old to generate habitual trips (work, school, etc.), and the generation of discretionary trips (access to shops, services, recreation, culture, family, etc.) in the activity time available.[2]

The new model generates a set of data covering all activity and trip-making behaviour for individual synthetic residents of the LMA. It does not include non-residents or visitors to the area. This change in model specification from a mobility probability by OD pair with no reference to persons and household, alongside the use of more recent data, resulted in 40 000 fewer trips than in previous estimates (from an earlier total of 1.1 million). The increasing spatial spread of the LMA helps to explain this since it reduces the relative weight of trips occurring within the city along with the fact that some trips that previously occurred across the border of the city (and were excluded from analysis) are now included in their entirety for the greater LMA analysis. The peak period assessment for the LMA also shows some change when compared to the city in that the LMA morning and evening peaks are of very similar intensities while in the city the morning peak is clearly stronger.

Conceptualisation of operational corridors

As noted previously, in order to optimise simulation speed, the entire synthetic trip population for the greater LMA was split into five functional areas and seven bi-directional corridors (or 14 uni-directional corridors) where, due to geographic proximity or infrastructure availability, travellers would have the greatest probability of being able to share their rides – particularly for Taxi-Bus services. Optimisation of trip allocation was carried out in parallel in each separate corridor. The results from this corridor-based analysis are then aggregated into four broad service areas: within the North Bank outside the city (A), within the South Bank (B), between the city and the external municipalities (C), and within the city (D).

Figure 4. **Functional areas and operational corridors used for the greater LMA analysis**



Source: ITF, Map tiles by QGIS.

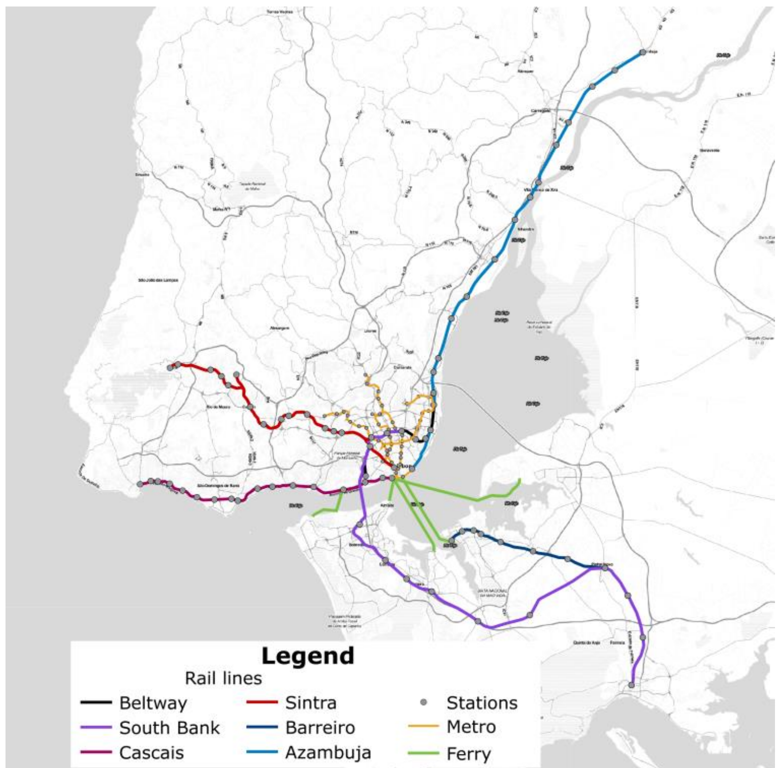
Table 5. **Corridor names, typologies and respective share of total number of trips in the LMA**

Corridor number (code)	Corridor name	Corridor typology	Share (%)
1 (A1)	Between municipalities in North Bank outside the city	(A) Mobility to/from Lisbon from external municipalities	5.96
2 (B)	South Bank	(B) Mobility with the South Bank	20.18
3 (C1)	Cross-river (towards the north)	(C) Mobility in the North Bank outside the city	3.61
4 (C2)	Cross-river (towards the south)	(C) Mobility in the North Bank outside the city	3.61
5 (D)	Inside Lisbon city	(D) City	22.2
6 (C3)	Sintra Corridor to Lisbon (towards Lisbon)	(C) Mobility in the North Bank outside the city	2.85
7 (C4)	Sintra Corridor to Lisbon (towards Sintra)	(C) Mobility in the North Bank outside the city	2.85
8 (C5)	Cascais Corridor to Lisbon (towards Lisbon)	(C) Mobility in the North Bank outside the city	1.74
9 (C6)	Cascais Corridor to Lisbon (towards Cascais)	(C) Mobility in the North Bank outside the city	1.75
10 (C7)	Vila Franca Corridor to Lisbon (towards Lisbon)	(C) Mobility in the North Bank outside the city	3.20
11 (C8)	Vila Franca Corridor to Lisbon (towards Vila Franca)	(C) Mobility in the North Bank outside the city	3.20
12 (A2)	Inside Vila Franca Corridor	(A) Mobility to/from Lisbon from external municipalities	11.39
13 (A3)	Inside Sintra Corridor	(A) Mobility to/from Lisbon from external municipalities	9.88
14 (A4)	Inside Cascais Corridor	(A) Mobility to/from Lisbon from external municipalities	7.50

Specification of new feeder services

Looking at the characteristics of the current mobility landscape in Lisbon – especially with regards to possibilities for integrating shared services with ferries, regional rail services and the metro – a new, composite, transport mode choice was introduced, based on high quality feeder services to high capacity public transport. The implementation of this new service class builds on Taxi-Bus optimisation routines and extends them to include connections to rail- and ferry-based public transport such that travellers can easily and comfortably be brought to their destination with time- and cost-efficient solutions.

Figure 5. **Rail, ferry and metro lines and stations used at the feeder service specification**



Source: ITF, Map tiles by QGIS.

The feeder service is specified as a pre-booking system in the model similar to Taxi-Bus services. Feeders use the same minibuses and have the same walk access constraints (no more than 400m at either end of the feeder service). Furthermore they serve those high capacity public transport trips where the traveller is within easy walking distance to the intended final trip destination (less than 10 minutes walking), or vice-versa. Differential weights are assigned to walking (three times more) and the connecting Taxi-Bus time (1.5 times more) as compared to the time spent travelling in the rail-based public transport or ferry. The feeder service specification in the model implies the following:

- The feeder service only serves one end of the trip. An OD pair badly served at both ends may lead to a direct Taxi-Bus or a Shared Taxi service.
- The walking segment linking the high capacity mode with the extreme (origin or destination) point of the trip will be less or equal to 10 minutes.
- High-capacity public transport trips of less than 5 km do not accept any transfers. Trips longer than 5 km may involve one intra-rail or intra-metro transfer.

- The total distance in the feeding part of the trip (walking + shared mobility) should always be shorter than the direct distance between trip origin and destination. This ensures that feeder services do not result in long detours from the most efficient path.

The dispatcher always considers a Taxi-Bus service running at the design speed (15 km/h linear speed). As with regular Taxi-Bus services implemented in the model, if a Taxi-Bus meeting minimum load factor constraints cannot be matched to the rider, they will be upgraded to a Shared Taxi instead. This occurs much less often for the feeder services than for other random point-to-point services because of the concentration of users at the high capacity mode station. When actually performing the service, the speed of Taxi-Buses is adjusted to the simulated speed on the road links they travel on, according to traffic volumes.

Allocation of trips to modes in the simulation

As this is a modelled scenario, and we do not have information on passenger preferences through, for example, a stated preferences survey focusing on the shared mobility services, this study uses an alternative approach to estimate mode choice under a radically new scenario. For this purpose, an expert analysis procedure was used, generating a rule-based lexicographic choice process based on socio-demographic and mobility attributes of the user. The envisaged selection process tries to incorporate the individual rationale in mode choice while preserving some room for the diversity of individual preferences (stochasticity). The mode choice process has been adapted from the previous study to incorporate the new available modes and a higher acceptance regarding the number of transfers in high capacity public transport (rail and metro) by people living further away from the city centre.

For trips in modes that continue to exist (walking and high capacity modes [metro, rail, ferry]), the mode choice is the same except when the reference situation was very penalising (i.e. very high access time, or two or more transfers in public transport solutions).

Trips in transport modes that are suppressed in the configuration with full adoption of shared mobility solutions are assigned to the Taxi-Bus or the Shared Taxi, following the rules indicated below. In trips for which a shared feeder to high capacity public transport leads to a shorter travel time, with no more than one transfer and walking access time not higher than 10 minutes, the user switches to the feeder service.

The evolution to a fully adopted shared mobility solution follows the market penetration of the new shared services. Consideration of possible migration to the shared services is made sequentially, with six classes as specified in the Table 6. The sorting within each of these six classes is made according to the number of trips per day and the total travelled distance (higher modal transfers for the higher number of trips or travelled distance).

In each of these classes, taken in sequence, users will compare their current option (if it remains active in a particular configuration being simulated) with the new options and decide based on the following rules:

- **Private car and motorcycle users:** Car users by default are migrated to the Shared Taxi alternative with some notable exceptions. Very short trips (less than 1 km), faced with the new context, migrate to walking; cars users owning a public transport pass select Taxi-Bus 70% of the time, but the trips with a faster solution based on a feeder service than on a Taxi-Bus are transferred to that option. In the other 30% of cases, they transfer to Shared Taxis.
- **Taxi users:** By default taxi users are migrated to the Shared Taxi alternative with some exceptions. Taxi users owning a public transport pass or with no car select Taxi-Bus, except where total travel time is shorter with a feeder service to high capacity public transport.
- **Pedestrians:** Current trips up to 2 km preserve this mode choice. With longer trips, we assume users may evaluate and preserve their mode choice or migrate to the modes available in the new

transport supply configuration (metro, Taxi-Bus, Shared Taxi or feeder service). The rules of choice among the non-pedestrian alternatives are the same as for current public transport users.

- **Public transport users:**
  a) *Bus and bus + high capacity public transport (metro, rail or ferry):* Bus users must change current mode. They are allocated the Taxi-Bus option with the exception of trips where travel time is shorter with a feeder service to high capacity public transport.

  b) *High capacity public transport (metro, rail or ferry):* They preserve their modal choice except when the access time or number of transfers is very penalising (more than 20 minutes access time and more than one transfer). In those cases they follow the rule of bus users, being allocated the Taxi-Bus option except where total travel time is shorter with a feeder service to high capacity public transport.

  c) *Private car + high capacity public transport (metro, rail or ferry):* These trips are allocated to feeder services into high capacity public transport with the exception of cases involving longer walking access at origin-destination and more than one transfer, which are transferred to Taxi-Bus.

Table 6. **Trips listed by order of consideration for modal transfer**

Order of class	Criteria	Percentage of all trips (%)
1	Taxi trips	2.59
2	Bus and bus + high capacity modes (metro, rail or ferry) trips	23.29
3	Very long walking trips (greater than 3 km)	0.18
4	Car commuting trips with paid parking and more than 3 hours parking	7.48
5	Other private car trips (free parking, or paid parking with less than 3-hour stay) and motorcycle trips	45.10
6	Trips in other modes (mostly high capacity public transport and short distance walking)	21.35

This procedure is implemented to each generated user (trip), allowing estimation of modal diversion in each shared mobility configuration. Because Taxi-Bus services are constrained to achieve at least 50% occupancy at some section of the route, the users that select Taxi-Bus and do not have that service available are diverted (upgraded) to the Shared Taxi option at no extra cost for the user. Since the Shared Taxi operator should not receive less revenue, in our cost estimates we assumed that the price differential of the upgrades would be spread across all Taxi-Bus users.

Table 7 indicates how trips in the reference case (2011) were re-attributed according to the lexicographical rules described earlier for a configuration where all car and bus trips were replaced by Shared Taxis and Taxi-Buses. The results show that individual motorised transport users (car, motorcycle and taxi) switch mainly to the Shared Taxi and Taxi-Bus options, while walking and metro users mostly remain in their reference mode, except in cases of long walking distances or bad metro connectivity, in which case they divert to motorised shared alternatives. Users that previously combined rail and bus modes mainly switch to shared alternatives, either due to poor rail/metro connectivity or due to long access time to metro and rail.

It is relevant to note that high capacity public transport modes (in direct access plus access by motorised transport (private car or bus in the reference case, feeder bus or Shared Taxi in the simulated scenario) grows from a market share of 12% (7%+1%+4%) to 17% (6%+11%) i.e. a relative growth of about 40% (17% ÷ 12% = 142%).

Table 7. **Analysis of mode diversion (whole LMA) – Passengers/day**

Mode in reference scenario (2011)	Mode in simulated configuration – Full adoption of shared mobility					
	Walk (%)	High capacity modes (%)	Shared Taxi (%)	Taxi-Bus (%)	Feeder service (%)	Total in reference scenario (%)
Private car (PC)	5	0	58	27	9	46
Motorcycle	9	0	46	41	4	1
Taxi	0	0	56	40	4	3
Bus	0	0	0	82	18	20
Walking	72	1	0	23	5	19
High capacity public transport (metro, rail or ferry)	0	71	0	2	28	7
PC + High capacity modes (metro, rail or ferry)	0	0	0	32	68	1
Bus + High capacity modes (metro, rail or ferry)	0	14	0	82	4	4
Total	16	6	28	38	11	

Overall modelling results of shared use mobility for the Lisbon Metropolitan Area

Aggregate impacts (traffic and emissions) for the Lisbon Metropolitan Area (LMA)

The overall, aggregate impacts resulting from the full-scale implementation of a shared mobility service for the whole of the LMA are generally more positive than the initial results reported for Lisbon Municipality (the city). As mentioned above in the "New activity-based model approach" section, these results for the city are slightly different from those published in the previous report (ITF, 2016a) due to the changes in the construction of the synthesis population and the mode choice model, but those small differences bring no change to their significance in policy terms.

The following sections present an overview of some indicators that are especially meaningful in terms of access and mobility in urban agglomerations. The set of results presented is a compromise between the need for a synthetic presentation in order to allow the reader to retain the key messages and the availability of very large set of outputs from the agent-based simulation.

Table 8 shows the key macro-level results of the scenario involving the full-scale replacement of all bus and car trips with shared mobility services, while maintaining walking and rail-based public transport. These results point to higher achieved load factors for Shared Taxis, higher load factors for larger Taxi-Buses (outside of the centre of the LMA), bigger reduction of vehicle.kilometres (VKM) travelled throughout the day with an even greater reduction at peak hours as well as lower CO_2 emissions for the LMA in comparison with the city.

There are multiple reasons why the simulation at the level of the LMA produces stronger results (in terms of reduction of VKM and emissions) than the simulation for the city but the main reason lies in the greater efficiencies derived from the adoption of Shared Taxi and Taxi-Bus feeder services to rail-based public transport. In the shared mobility scenario for the LMA, rail-based trips accounted for 17% of all trips whereas in the reference scenario, they only accounted for 12% (Table 7).

Table 8. **Overall impacts of full implementation of shared mobility at the scale of the LMA**

Aggregate indicators	LMA	Lisbon	Outside Lisbon
Avg. pax on board (Shared Taxis)	2.3 (peak 3.0)	2.1 (peak 2.7)	2.4 (peak 3.2)
Avg. pax on board (Taxi-Bus)	4.3 (8 seat) / 11.9 (16 seat) Peak: 4.8 (8 seat) / 12.9 (16 seat)	4.8 (8 seat) / 10.7 (16 seat) Peak: 4.6 (8 seat) / 12.3 (16 seat)	4.1 (8 seat) / 13.2 (16 seat) Peak: 4.8 (8 seat) / 13.6 (16 seat)
VKM (weighted) all-day - % reduction compared to reference case (2011)	-48%	-40%	-51%
VKM (weighted) peak-hour - % reduction compared to reference case (2011)	-55%	-44%	-59%
CO_2 emissions	-62%	-53%	-67%

Note: Pax = passenger; VKM = vehicles.kilometres.

In all cases the indicators (except for the occupation of the 8-seater Taxi-Buses in the morning peak) for the LMA are better than for the city. This is due to multiple reasons including:

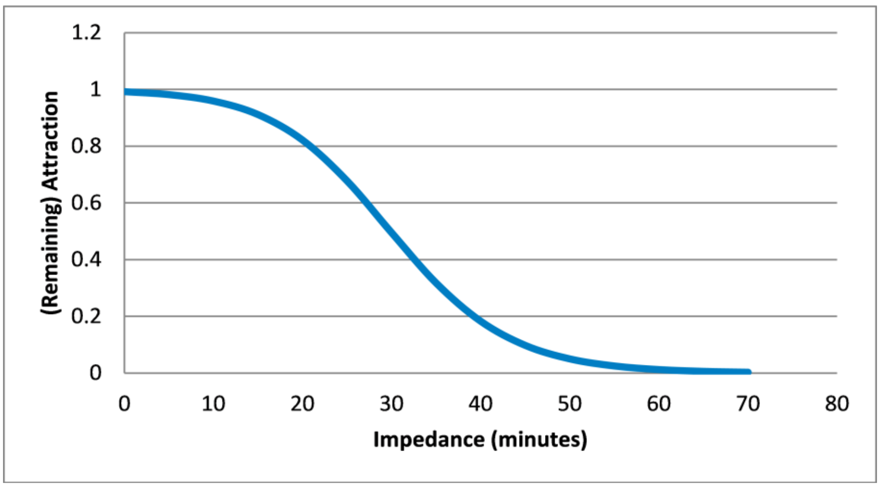
- Private cars are the largest contributor to VKM and to CO_2 emissions in the reference case, and their part of passenger.kilometres (PKM) globally for the LMA is 63.4 % whereas in the city it is 47%. So, the volume (of traffic and of emissions) available for reduction is bigger for the LMA.
- Whereas in the city, the transfer from private cars is made to Shared Taxis and Taxi-Buses (which are also emitters, albeit at lower levels per PKM due to the higher occupation), in the case of the LMA a substantial part of those transfers are made to the high capacity public transport which is mostly electric rail (we did not count for the emissions in the generation of the electric power), the exception being the ferries with a very small part of that set. In the shared mobility scenario for the LMA, high capacity public transport trips accounted for 17% of all trips whereas in the reference scenario, they only accounted for 12% (Table 7).
- Average occupation of Shared Taxis outside Lisbon is higher because a large part of those trips are into or coming out of Lisbon, and this (relative) concentration at one of the extremes of the trip makes ride sharing more efficient.
- In the LMA the part of the 16-seaters in the Taxi-Bus fleet is by far larger (contrary to what is found for the city, where 8-seaters dominate), and the higher occupation they show in relation to the city is also due to the feeding role they play for high capacity modes and in serving the pendular trips into/out of Lisbon. In the LMA the 8-seaters mostly do complementary functions serving less dense demand flows.

Accessibility levels to jobs in the Lisbon Metropolitan Area

Accessibility based on public transport modes increases very strongly with the introduction of shared mobility services. While only a few cells and a limited part of the population could access a considerable share of employment within an acceptable time (distance decay function as an S-curve calibrated for the LMA in the reference case [2011]), the increased access with shared modes and their mostly direct services are more a function of spatial distance to the job market than of public transport provision quality.

Using the S-curve to represent attraction decay, accessibility calculations produce results in terms of "effective access to jobs" (or other opportunities and services), meaning the number of jobs that we should expect to be considered as accessible by people in an acceptable (to them) timeframe. When data is available with the adequate level of geographic precision, this produces results that better represent reality than the more traditional indicator of "number of jobs within 30 minutes", as explained in Corporate Partnership Board report *Linking People and Places: New ways of understanding spatial access in cities* (ITF, 2017). In this section we use the S-curve calibrated for users of public transport in the LMA.

Figure 6. **S-curve representing the attraction decay for accessibility calculations (using public transport)**



In all the LMA areas, although with some differences in terms of acceptable waiting time, people can travel at a linear speed of at least 15 km/h with the Taxi-Bus service. This allows a huge increase in the quality of access and moves the good access locations beyond the city, where currently many jobs and public services are concentrated.

Table 9. **Quantitative distribution of access to jobs**

% of LMA population enjoying certain percentages of accessible jobs in LMA region	25%		50%		75%	
	Current mobility	Shared mobility	Current mobility	Shared mobility	Current mobility	Shared mobility
Within the city	4.17%	19.63%	0%	19.63%	0%	0%
Within the LMA (including city)	4.17%	76.05%	0%	57.36%	0%	0%

Analysing the very synthetic results in Table 9 it is possible to draw a couple of important conclusions:

- In the reference case scenario, the 4.17% of the total population in the LMA, with access to at least 25% of the jobs, are comprised totally of residents of the city.
- When shared mobility solutions are introduced, we can see how equity of accessibility significantly improves, both for the city and the LMA: for the case of the city, all its residents (representing 19.63% of the total LMA population) have effective access to at least 50% of the jobs; for the case of the LMA as a whole 76% of its residents have effective access to 25% of the jobs in the LMA and still more than half (57%) have effective access to 50% of those jobs.

This very strong increase in access levels also reduces the spatial asymmetries in the LMA as shown in the following table and maps.

Table 10 represents the values of P90, i.e. the 90th percentile (grid cell with 10% highest accessibility to jobs) and of P10, i.e. the 10th percentile (grid cell with 10% lowest accessibility to jobs), in the reference scenario and in the scenario with shared mobility solutions, as well as their ratio. Separate values are shown for the city, the remaining corridors on the North Bank, the total area in the South Bank, and the whole of the LMA. In all cases, reference is made to the whole set of jobs in the LMA.

Table 10. **Percentage of LMA jobs in the 10th and 90th percentiles of grid cells for the reference and the shared mobility scenarios**

Geographical area	P10		P90		P90/P10	
	Current mobility (%)	Shared mobility (%)	Current mobility (%)	Shared mobility (%)	Current mobility (%)	Shared mobility (%)
LMA	0	3	3	69	112.11	19.80
City	2	64	27	72	13.66	1.12
South Bank	0	3	2	57	60.13	16.63
Sintra corridor	0	11	3	71	52.00	6.65
Cascais corridor	0	16	2	72	18.58	4.44
Vila Franca de Xira Corridor	0	2	1	58	125.09	33.45

While introducing shared mobility solutions in the city delivers remarkable results and reduces asymmetry significantly (reduction of the P90/P10 ratio). The results for the LMA region are even more striking, such that for all corridors outside the city the P90 value with shared mobility is more than two times better than it was for the city in the reference case scenario.

Figure 7 shows, for each cell, the ratio between the number of effectively accessible jobs after full deployment of the shared mobility services (using Taxi-Bus and feeders + high capacity public transport) and in the reference case (using public transport), the darker background colours being associated with higher ratios. To make it clear, this means the rate by which the number of accessible jobs would grow for residents in each cell.

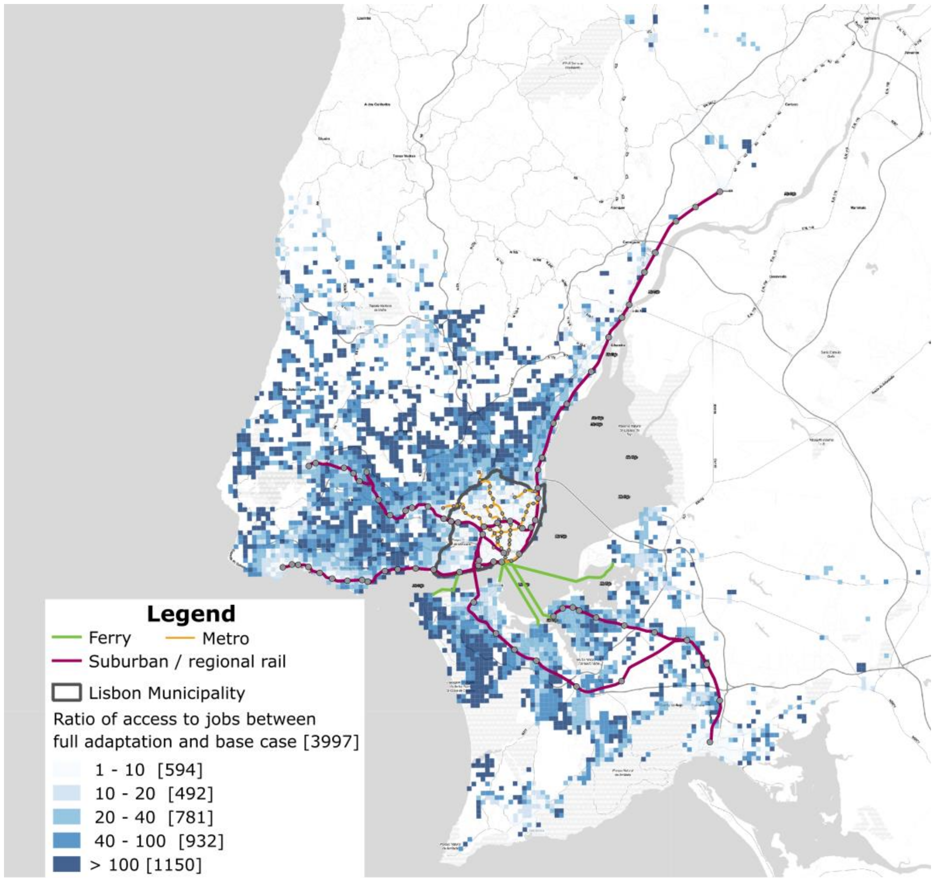
While in the city most cells have a ratio between 1 and 10 (with a few between 10 and 20), roughly one half of the total number of cells in the LMA this ratio is above 40, while about 25% of the cells have a ratio above 100. In essence, what this means is that the access to jobs by 50% of residents increases by a multiple of 40 and for 25% of people by a multiple of 100. This would represent a radical transformation of the conditions of access to jobs in the LMA.

By considering the shape of the attraction decay S-curve in Figure 6 it is easy to understand how such high values can occur: for instance, changing from a very penalising situation in which travel time by public transport to a job location is 70 minutes - which corresponds to a willingness to travel of 0.3% - to another in which the travel time to that same job is a quite acceptable 30 minutes - corresponding to a willingness to travel of 49% - leads to a ratio (of willingness to go and thus of accessibility to that job) between these two situations of 163.

The geographical distribution of the darker coloured cells, mostly far away from the railway lines, conveys a very powerful message of how shared mobility and in particular the feeder services combined with the existing high capacity public transport (mostly rail) contribute to a radical transformation of access to jobs across the LMA, and in particular outside the Lisbon city. And it provides a logical explanation to why the usage of private cars currently is so high for people living in those areas.

The analysis presented here only covers access to jobs but the benefits of adoption of shared mobility solutions would be similar regarding access to essential public services like health and education, as already shown by ITF (2016a).

Figure 7. **Ratios between the numbers of effectively accessible jobs with shared mobility solutions and in the reference case**



Note: (using public transport in both cases).
Source: ITF, Map tiles by QGIS.

Performance measures for shared mobility solutions for the Lisbon Metropolitan Area

This section deals with some of the key micro-scale aspects directly related to the shared mobility services, both from the clients' and operators' perspective. Values are presented with different types of geographical aggregation in different tables, depending on what was considered the most relevant for interpretation of results.

The first indicator analysed is waiting time for Shared Taxis services. Since car drivers value the permanent availability of their car quite highly, this is a very important attribute to be able to persuade current car drivers to adopt Shared Taxis, and that is the reason why the parameters in the model specify rather low maximum acceptable waiting times.

The results in the simulation are quite encouraging: in the city, average waiting times for Shared Taxis (across the whole 24 hours) are less than three minutes, and for all the other corridor types they are just around five minutes. And the 75th percentile (only 25% of the passengers wait more than this) the values are below three minutes for the city and below seven minutes for all other corridors. Table 11 shows these values, as well as those for the Taxi-Buses.

In all categories of service and all corridors, median waiting times are very low, and even the 75th percentile values are below the current median values for most cities in the developed world.

The observed waiting times show that the performance within the city, which has greater density, ensures lower waiting times. Some lower-demand corridors have an additional five-minute waiting time tolerance, because they do not have an associated vehicle depot. So, when a vehicle goes idle there, it goes to a depot in another corridor and this increases the waiting time and empty kilometres to reach the next client in that depot-less corridor.

It is also interesting to note that in all cases the average is higher than the median, which reflects a stronger presence of low waiting times and a very small number of high waiting times.

Table 11. **Distribution of waiting times for Shared Taxis and Taxi-Buses (by corridor type)**

Corridor type	Waiting time (minutes)				
	Mode	Percentile 25% (P25)	Median (P50)	Percentile 75% (P75)	Average
A	Shared Taxi	1.16	2.10	6.80	4.43
	Taxi-Bus	6.18	8.49	13.49	10.23
B	Shared Taxi	1.07	1.93	6.70	5.14
	Taxi-Bus	7.05	9.50	14.49	10.55
C	Shared Taxi	1.30	2.38	6.67	4.56
	Taxi-Bus	5.49	9.89	13.52	10.26
D	Shared Taxi	0.93	1.62	2.88	2.46
	Taxi-Bus	1.50	4.39	8.52	5.04

Active fleets

After each simulation run representing the generation of demand, the dispatch of vehicles to serve the clients, and the routing of those vehicles on the road network, another computer model allocates duty cycles of the vehicles to work shifts that correspond to legally acceptable durations. This is done through an optimisation program with the objective of minimising the size of the vehicle fleets required and thus making the best use of those vehicles. Like in earlier studies, two types of shift were considered: four hours and eight hours, the latter with a one-hour meal break.

Figure 8 shows the numbers of active vehicles in each category along the hours of the day after consideration of the legal limits of working time of their drivers, and thus including the time spent for meal breaks in the eight-hour shifts or for changing drivers at the end of the work shifts.

The maximum number of Shared Taxis that could operate is 42 245. This represents 4.1% of the number of registered private cars in the LMA, and 9.4 times the current number of licensed taxis in the LMA (not counting ride service operators, such as Uber and Cabify, which were also not present in the reference year of 2011).

In the case of Taxi-Buses (Figure 9) the general shape of the curves of fleet size in operation is similar to that of the Shared Taxis, with strong peaks around 08:00 and 17:00. The fleet size of 8-seater Taxi-Buses is 5 452 vehicles, and for 16-seaters, the figure is 28 883 vehicles. Thus the total Taxi-Bus fleet size is 34 335 vehicles and its total capacity is 43 616 (in 8-seaters) + 462 128 (in 16-seaters) = 505 744 passengers, all seated.

This is much more than the current fleet of 3750 buses, some 9.16 times. If we compare the number of offered places the ratio is quite different, as the total capacity of the current bus fleet in the LMA is 286 482 of which 156 102 (54.4%) is seated. Thus the capacity ratio of the Taxi-Bus fleet to the existing fleet is 505 744 / 286 482 = 1.77.

As mentioned earlier, the intensities of the morning and evening peaks are very similar when considering the LMA as a whole. One consequence is that a larger share of the Shared Taxis will be doing eight-hour shifts, with a very stable fleet size active between 07:00 and midnight, with the four-hour shifts essentially mobilised to cover the peaks.

Figure 8. **Number of vehicles (Shared Taxi) in operation**

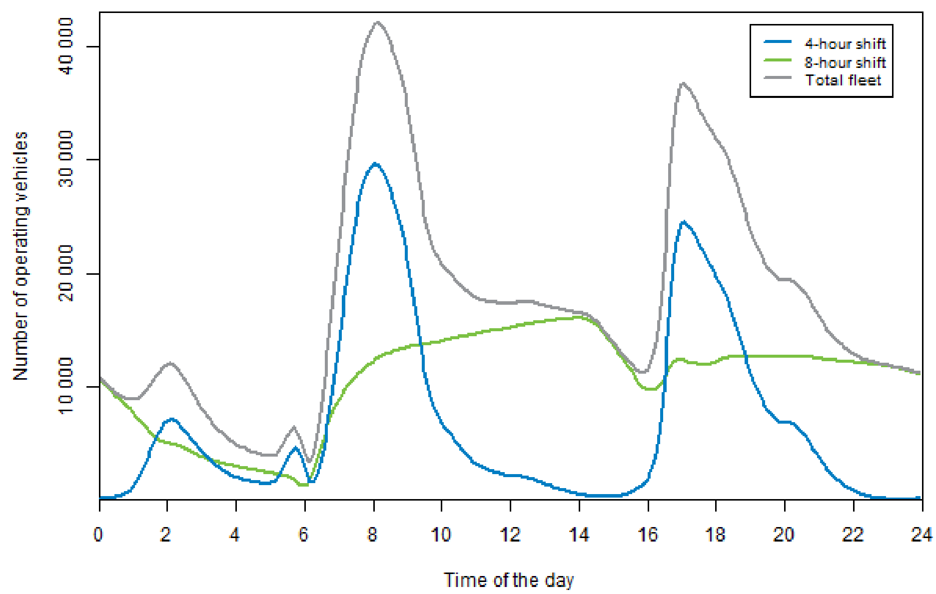
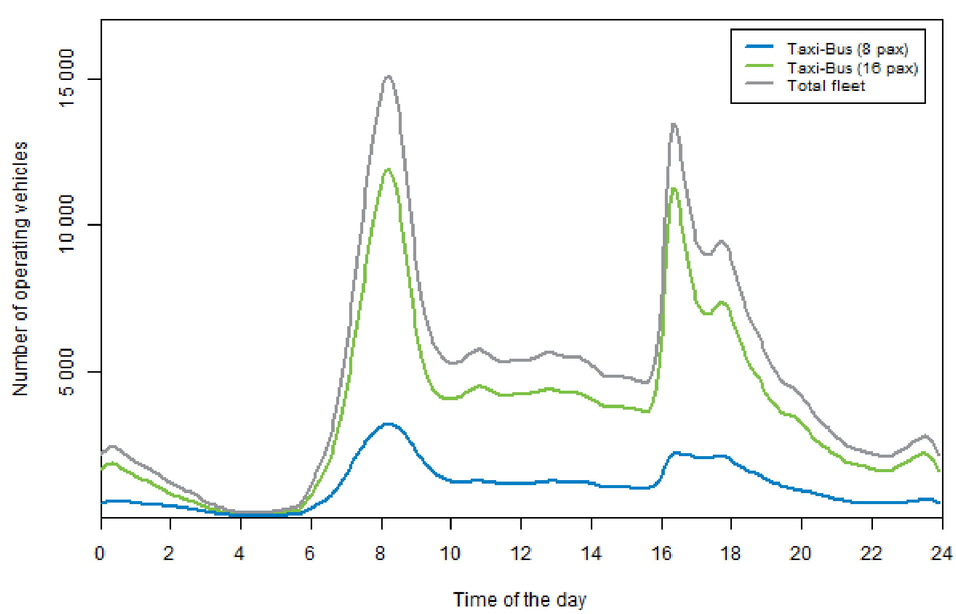


Figure 9. **Number of vehicles (Taxi-Bus of capacity 8 and 16 pax) in operation**



With the Taxi-Bus fleets, we can see that the 8-seater fleet has a smaller but quite stable presence, whereas the 16-seater fleet has a much larger share of the whole supply in this segment and closely follows the global demand. The reason for this is strongly associated with the use of these larger vehicles in the feeder services to the public transport high capacity modes stations.

Regarding parking needs, the conclusion is similar to that of earlier studies: some 95% of the total necessary parking space would be freed up for other uses. In the city, this released space would compromise all surface parking, plus at least half of the parking supply in parking garages. In the rest of the LMA, the supply of public parking garages is much smaller, and that would imply possibly still leaving some parking spaces on the surface for the shared vehicles. But those remaining parking places could easily be selected in places that would be of less interest for the new public interest uses allocated to the released areas.

Usage levels of the Shared Taxi vehicles

As a consequence of the above mentioned optimisation program, these Shared Taxis would have an intense daily use of on average 389.5 km, for an average duration of operations of 8.45 h. For each eight-hour shift, they would drive on average 313 km and in a four-hour shift on average 131 km.

In terms of average time usage, time in movement represents 82.6% of shift time, and paid time (with passengers on board) represents 79.8% of the time in movement, the rest being time from and to depot with no clients on board.

The corresponding average operating speed is relatively high but it reflects the good quality of the road network in the LMA (with a strong presence of motorways) and their uncongested situation at all hours of day and night in the simulated scenario with a strong reduction of traffic volumes.

These very high usage levels correspond to a very efficient use of the vehicles and of labour, and are at the basis of the relatively low operating cost per vehicle.kilometre. This, coupled with the good occupation levels, leads to very low breakeven prices per passenger.kilometre as will be shown further down.

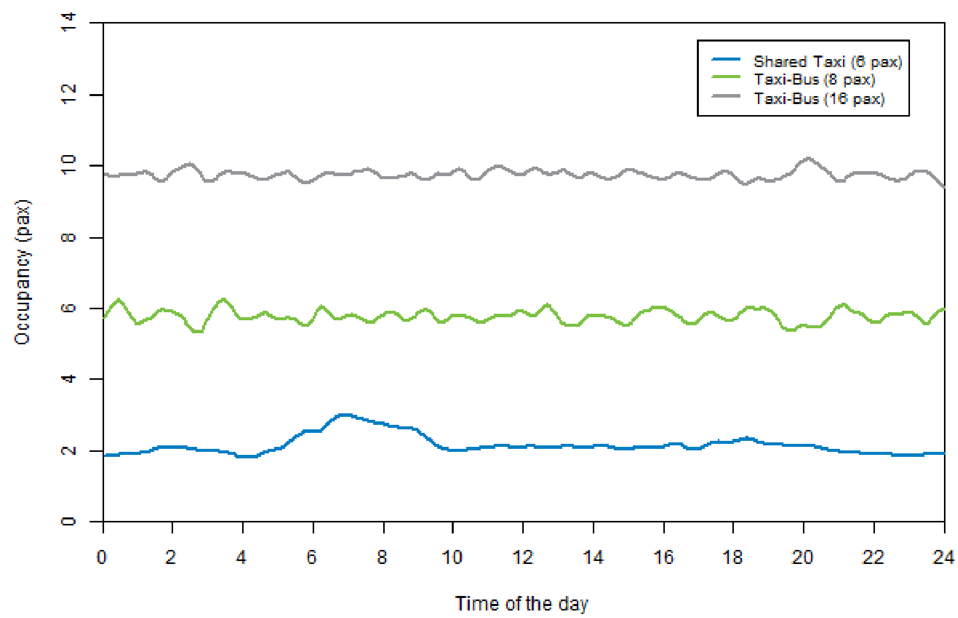
Average occupation of vehicles throughout the day

High average vehicle occupation levels of Shared Taxis and Taxi-Buses are critical not only for the economic efficiency of the services but also for the reductions of traffic volumes (and associated congestion) and emissions. This was the reason that led to the concept of "upgrade" from Taxi-Bus to Shared Taxi, taking advantage of the higher flexibility of the latter, and ultimately leading to stable levels of average occupation in the two Taxi-Bus categories (which include the feeder services).

For the Shared Taxis, Figure 10 shows that average occupation never goes below 2.0 and reaches values at or above 2.5 for a few hours during the morning and evening peaks. The daily average for the LMA is 2.3, with the value for the peak at 3.0 as shown in Table 8.

Overall, each of the three types of shared vehicles has quite stable levels of occupation in the simulation, which suggests that the procedures adopted in the simulation for management of the fleet size are adequate to ensure good economic performance of those that are "on duty" at any time of the 24-hour cycle.

Figure 10. **Average occupation per vehicle type**



Passengers upgraded from Taxi-Bus to Shared Taxi throughout the day

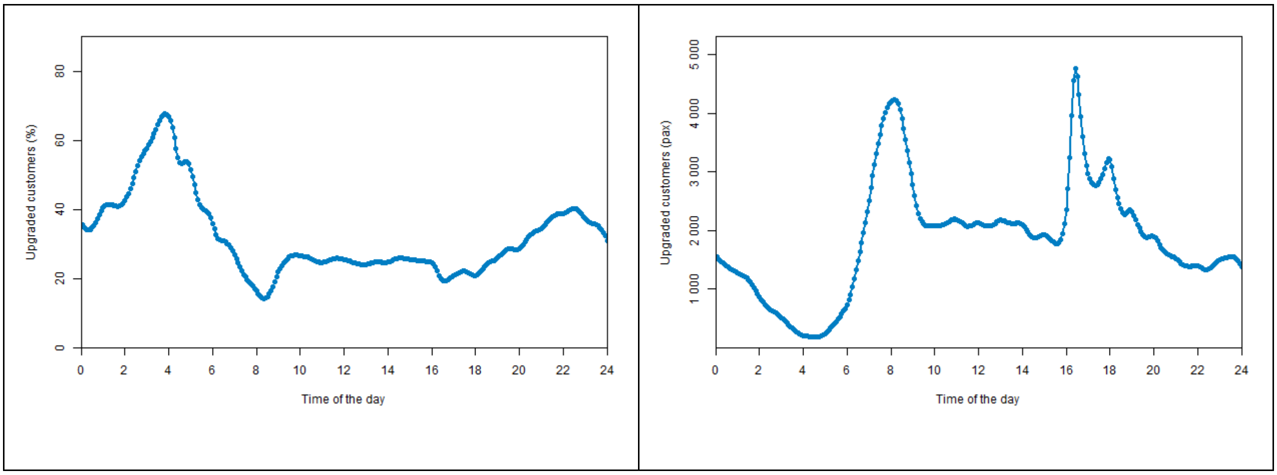
This is an important feature of our concept of shared mobility solutions.It allows using a much more flexible instrument (the Shared Taxi) to better serve specific mobility requests of clients who do not find enough "partners" with simultaneous and broadly similar travel requests to justify the deployment of a Taxi-Bus.

Since we are suggesting that those passengers pay the same as in the Taxi-Bus service with the same origin and destination, this scheme would also raise some administrative questions of fare collection and compensation to the Shared Taxi operator, but the fact that all of these clients and operators will be digitally connected suggests the technical treatment of those questions manageable.

Figure 11 indicates the incidence of the service upgrade and offers interesting perspectives:

- In relative terms, this scheme has a very high incidence from 02:00 to about 04:30, reaching almost 70% of all passengers asking for a Taxi-Bus service, and rather low incidence between 08:30 and 9:30, coming even a bit lower than 10% of those passengers. Then during most of the day it is quite stable, around 20%, then moving up and down between 20% and 40% until 02:00.
- In absolute terms, we have a different perspective: the lowest numbers are in the night hours when the percentage is highest, which is also associated with the fact that the high capacity public transport modes are not operating. And the highest peaks are at moments of low percentage, but associated with the general mobility peaks in the morning and afternoon periods.
- The averages across the whole day are at 23.5% (average weighted by the numbers in each period) and 22 376 passengers/hour.

Figure 11. **Passengers upgraded from Taxi-Bus to Shared Taxi**



Note: In percentage of Taxi-Bus clients (left) and in absolute numbers per day (right) throughout the day

Modal shares throughout the day

The evolution of modal shares throughout the day in the reference case, presented in Figure 12, shows a clear dominance of private car use across all hours of the day although with some variation. First, there is a much stronger share during the night period when there is no offer of scheduled public transport, and second there are strong reductions (but still retaining the strongest position and more than 50% of the total passenger.kilometres [PKM] transported) in the morning and evening peaks. Between the peaks and in the evening after the peak its market share is always between 70 and 80%.

The next modes in terms of PKM are buses and walking, with the former approaching 20% market share at the morning and evening peaks, and hovering around 10% for the rest of the operating period, and the latter coming from rather low values before the morning peak to between 6% and 8% for the rest of the day until midnight.

The situation of modal shares under the shared mobility scenario is naturally quite different. Shared Taxis are the new dominant mode, reflecting the preferences of the former private car drivers, still retaining shares around 50% for most of the day between 08:00 and 01:00. During the night, the absence of the high capacity public transport modes and the greater difficulty of reaching the minimal occupation thresholds defined for Taxi-Buses, because of the lower density of demand, bring the role of Shared Taxis to values around or even above 80% of the total mobility.

The second strongest mode is the 16-seater Taxi-Bus, which even briefly surpasses the Shared Taxi during the evening peak. A curious phenomenon can be observed regarding the market shares of Taxi-Buses in the morning and evening peaks: in the morning peak there is a reduction of its role, particularly for the 16-seaters, partly (but not wholly) replaced by the 8-seaters, whereas in the evening peak the 8-seaters even diminish their presence and the 16-seaters grow beyond the market share of the Shared Taxis. This probably has to do with the concentration of demand in space and time, but only a more thorough analysis will allow a full explanation.

Figure 12. **Modal shares throughout the day (in PKM) – Reference case**

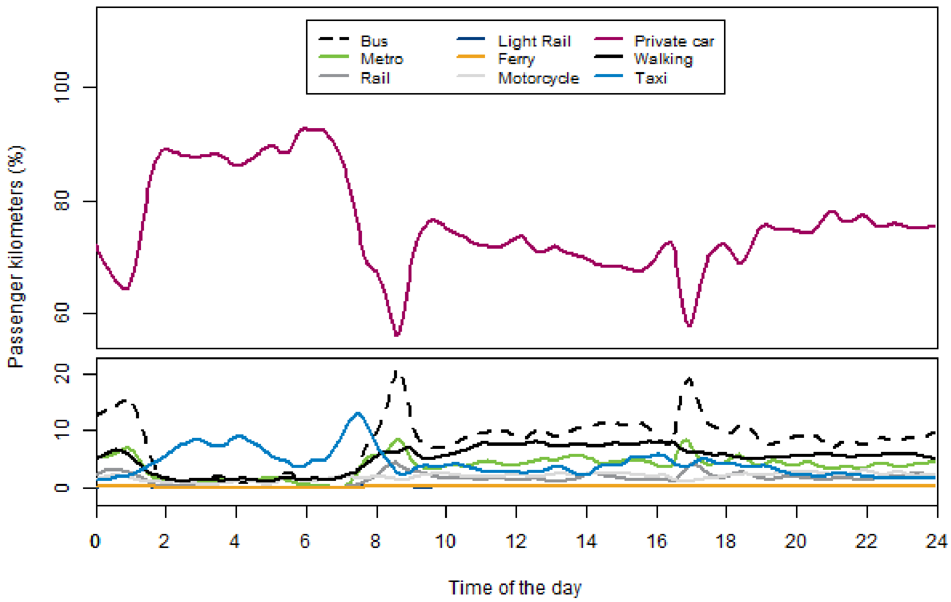
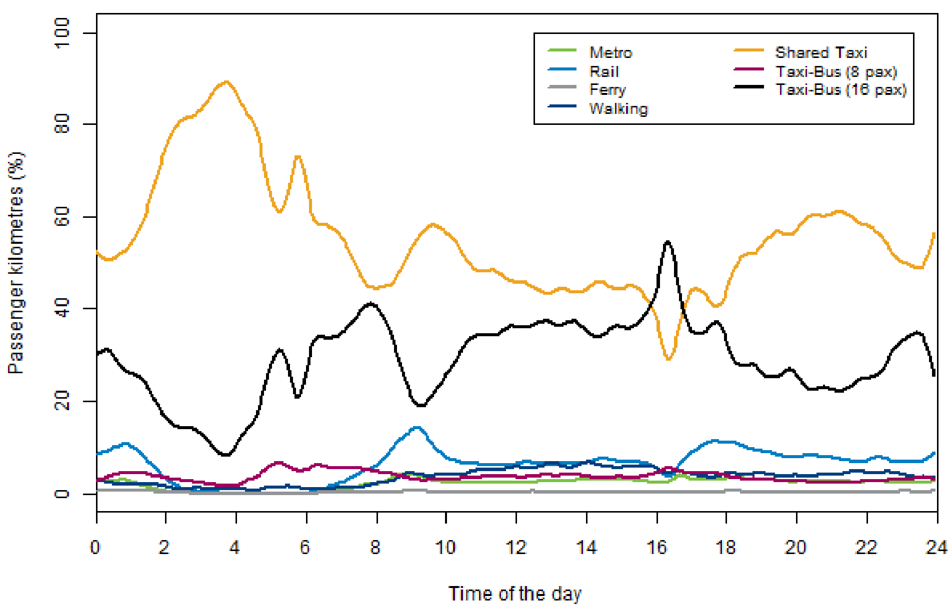


Figure 13. **Modal shares throughout the day (in PKM) – Shared mobility**



Use of high capacity public transport modes

As mentioned above, the introduction of very efficient feeder services into the stations of high capacity public transport modes makes their usage very attractive and significantly increases their total patronage in relation to the current situation.

Table 12 presents a synthesis of those impacts in terms of boardings (accessing the stations by walking or low capacity modes), separated by mode (rail, metro, ferry), with a subsequent division of the rail mode by lines.

Table 12. **Daily passenger boardings at the stations of high capacity public transport modes**

High capacity line or system	Reference case				Shared mobility					
		Access modes (%)				Access modes (%)			Variation boardings	
	Boardings	Private Car	Bus	Walk	Boardings	Taxi-Bus	Shared Taxi	Walk	Absolute	%
Rail - Azambuja	33 142	5.8	39.6	54.6	56 315	57.6	17.9	24.5	23 173	70
Rail - Barreiro	8 926	3.9	60.2	35.9	19 360	63.3	22.3	14.4	10 434	117
Rail - Cascais	75 291	2.6	44.8	52.6	104 992	60.0	12.1	27.9	29 701	39
Rail - Sintra	88 167	3.2	32.0	64.8	147 270	57.5	12.8	29.7	59 103	67
Rail - Beltway	11 034	4.4	25.3	70.3	15 945	53.8	16.4	29.8	4 911	45
Rail - South Bank	19 901	5.3	36.7	58.0	55 444	79.6	13.9	6.5	35 543	179
Metro	261 570	5.0	31.0	63.9	331 760	44.4	11.9	43.7	70 190	27
Ferry	12 745	8.5	32.0	59.5	11 424	61.2	19.8	19.0	-1 321	-10
Sub-total rail	236 461	3.9	38.1	58.0	399 326	62.1	15.0	22.8	162 865	69
Total	**510 776**	**4.4**	**36.5**	**59.1**	**742 510**	**59.8**	**14.8**	**25.4**	**231 734**	**45**

The main conclusions that can be drawn from these values are:

- There is a very significant increase in the number of boardings in the high capacity public transport modes system, with an overall gain of 45%, or 231 734 passengers per day. In relative terms this is even more impressive for the suburban railway system, with overall gains of 69%, and in particular for the South Bank (179% gain), the Barreiro (117%), Azambuja (70%) and Sintra (67%) lines.
- There is some loss on the ferries in compensation of the huge gains made on the South Bank line. In absolute terms, there is still a net gain of 34 222 passengers per day in favour of the high capacity modes crossing the river, but the advantage of the rail over the ferry is that it has multiple stations on either side of the river, thus providing more people convenient access to them, walking on one side and via Taxi-Bus on the other (only one transfer is allowed in the model).
- If we consider the catchment of the high capacity modes in the reference case, walking is the dominant mode with 59% overall and 58% in the sub-total for rail and only the Barreiro line was below 50%. This contrasts with the scenario of shared mobility in which the dominant mode is the Taxi-Bus, with a market share of just about 60% overall, 62% in the rail sub-system, and above 50% in all systems and lines except in the metro. Walking is reduced to an average of 25% overall and 23% in the rail sub-system, with more than 40% only in the metro system. These numbers are a very strong demonstration of how the high capacity modes have been under-utilised because of the inefficient solutions adopted for bringing people to its stations.

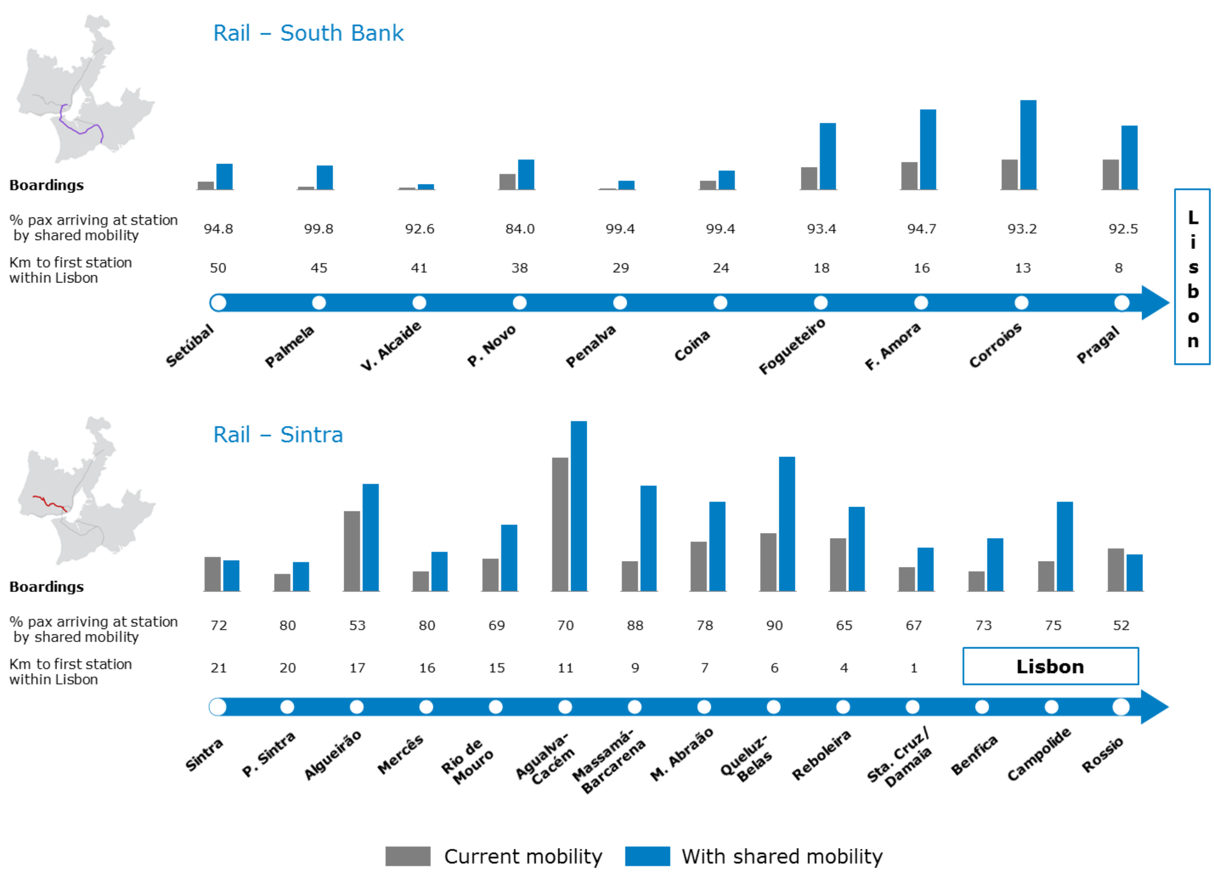
It is interesting to look in greater detail at the cases of two rail lines with somewhat different situations regarding the growth of their boardings and the role of shared mobility feeding services in the simulated configuration: the South Bank line and the Sintra line, shown in Figure 14. Each line has its own schematic linear presentation, showing the sequence of stations with bars proportional to the total number of boardings in the reference case and in the shared mobility scenario, and the percentage of those boardings that are fed byshared mobility services, mostly by the feeder Taxi-Buses.

In the case of the South Bank line, with a total increase of boardings of 179%, quite strong increases can be seen especially in the stations closer to Lisbon, with (in all stations) a high or very high part of those boardings being fed-in with shared mobility services.

In quite a few of these cases the percentage of boardings using shared mobility feeding services is even higher than the actual increase in the number of boardings. This is because a significant part of those boardings corresponds to modal shifts by people that already use the station but currently walk long distances, or use Park&Ride or regular buses to get there.

In the case of the Sintra line, with a total increase of boardings of 67%, the percentage of boardings by shared mobility services is lower, in some cases "only" around 60% instead of the values around 90% found in the South Bank line. The reason for this is that relatively dense housing developments were built within walking distance of those stations in the period 1950-1990. The percent increase in the number of boardings occurs precisely in the stations that were opened at later dates, for which there are fewer residents within walking distance.

Figure 14. **How feeder services affect total boardings at different stations along a suburban railway line**



The key conclusion from this analysis is that shared mobility services are highly symbiotic with high capacity public transport modes (typically rail) in suburban areas thus equipped.. Shared mobility services provide a much better quality of access to the stations (at reduced cost as seen below) and thus increase the demand for that high capacity mode; and vice versa, the concentration of demand on one the extremes (start or end) of the shared ride leads to a higher occupation of the shared mobility vehicles (Taxi-Buses and Shared Taxis) and with it improves the efficiency of their operation.

Moreover, there is an even stronger reduction of road-based vehicle.kilometres and CO_2 emissions by having a part of many trips currently done by private car replaced not by more efficient (shared mobility) road vehicles but by electrified rail services.

Breakeven prices for shared mobility modes

Since the general outlook of the operations of the shared mobility system at the scale of the LMA as presented in this report is quite similar to that presented by ITF (2016a), the breakeven prices for per passenger.kilometre (PKM) in each of the two new modes are also very favourable. If fact, they are even a bit lower for the Taxi-Buses in the LMA because of the higher efficiency achieved through the higher occupation rates with the feeder services.

Since prices per PKM in the current situation were taken from company reports and thus are based on actual travelled distances, in the earlier reports we were calculating the breakeven price per PKM also using the travelled distances by the passengers in the simulated scenarios.

But ride sharing will generally lead to a higher ratio between the travelled distance and the direct route distance (and the travelled distance may change from one day to the next), so in this report we calculate the breakeven price per PKM in the simulated configurations on the basis of their direct route distance. This is the reason why the breakeven prices per PKM (in percentage of current prices per PKM) presented in this report are higher than those in the 2016 report. But in fact, comparing strictly on the same basis, the breakeven prices for the LMA (covered in this report) are a bit lower than those for the city (covered in ITF, 2016a).

Using the same approach for consideration of capital costs, operational costs (including labour), back office costs and profits as in that earlier report, the average breakeven prices estimated applicable per PKM in the LMA (which is supposed to be identical across the whole geographical area) are, for the Shared Taxis, 30.5% of the current equivalent price for the single user taxis (and still lower than the current equivalent price for public transport, at 73% of that price).

For the Taxi-Buses, the breakeven price per PKM is 40.2% of the current equivalent price paid by the public transport user and 26% of the current equivalent total cost considering the price paid by the user plus the subsidy paid by the State (Metropolitan Area Authority) to the operators.

These breakeven prices obtained in the simulation, using realistic assumptions on production factor prices, are very encouraging regarding what could be the public acceptance of these high quality services.

To conclude, it is possible to state that, in spite of the much lower population and job densities, full deployment of shared mobility solutions for the Lisbon Metropolitan Area, with still very high standards of quality of service, would have the same kind of macro impacts as those presented in the earlier report (ITF, 2016a) for the Lisbon city centre including:

- very significant reduction of traffic volumes and CO_2 emissions
- very significant increases of accessibility both in average and its equitable distribution
- quite efficient use of the capacity in the shared vehicles, with the corresponding impacts on the prices per passenger.kilometre
- very strong reduction of parking needs across the whole of the LMA, allowing the corresponding release of the associated public space to other uses of much higher amenity.

On top of these impacts, there would be a significant contribution for a higher usage of the available infrastructure capacity in the high capacity public transport modes (bringing them to patronage levels of some 25 years ago). On the other hand, the availability of these high capacity modes is essential to achieve the system’s high levels of efficiency in spite of the lower densities, as it creates the natural demand concentration points that quite naturally lead to high occupation of the (quite small) shared vehicles.

3. How to deploy shared mobility services? Lessons from transition and market structure scenarios

The results discussed previously derive from a scenario that assumes 100% replacement of all car and bus trips by a mix of new shared modes, rail-based public transport and walking (cycling is included in the model but was not activated due to extremely low mode shares). As such, it is a scenario that indicates the types of changes and the potential magnitude one might see from the adoption of shared mobility services at the metropolitan scale, rather than a forecast of a real situation. This type of scenario is interesting as a conversation starter around the potential for shared mobility but it is not a blue-print for implementing such systems. Furthermore, the impacts experienced at full implementation levels are likely to be quite different from those experienced during the transition as the uptake of these services grows and as new markets develop around the delivery of these services.

There are multiple potential uptake pathways that could be explored. For the purposes of this work, we selected two to test, both associated with plausible transport policy approaches: The first looks at gradually increasing the uptake of shared mobility according to a plausible early adopter pathway, guided by specific step-wise policy interventions. The second at the impact that changes in market structure (monopoly vs. multiple service providers operating under different market rules or business cases) have on fleet requirements and overall travel.

All of these scenarios result in less efficient system performance than the 100% “all-in” scenarios modelled previously, but they are worthwhile investigating since system efficiency is only one of a number of valid criteria that authorities might use to guide the deployment of such services.

Targeted early adopter pathways

An early adopter pathway would deploy shared mobility services in a targeted, policy-based way so that they represent an attractive, or even a better alternative, as compared to current types of trips and use cases. In this section we explore some of these targeted early adopter pathways. For this we made use of the ranking of users by propensity to consider modal shift (as presented above in the section “Allocation of trips to modes”).

In the first instance, we test a scenario at the level of the greater LMA where shared mobility services replace all bus services with Taxi-Bus or feeder services, and single user taxi services with Shared Taxi services. These are pure supply-side measures than can be enacted by the metropolitan agency in charge of mobility, necessarily preceded by national legislation to authorise such services as they currently do not exist. Trips corresponding to these types of supply (scheduled buses and single user taxis) account for approximately 26% of all trips in the LMA and for 21% of the overall passenger.kilometres travelled in the LMA.

Table 13 shows the results for this targeted trip replacement scenario. In this scenario, all trips previously taken by bus (77.3% of the trips targeted in this scenario) are allocated to either Shared Taxis or feeder services to high capacity modes of public transport, whereas slightly less than half of those travellers using taxis (representing 10% of the trips targeted in this scenario) are allocated to Taxi-Buses or feeder services. The reason for this partial shift from single user taxis to Taxi-Bus or feeder services is that currently people may have to use a taxi because no suitable public transport service is available at the place and time they need it. This scenario is designated as “baseline adoption” scenario.

Table 13. **Targeted early adopter scenario: Baseline adoption scenario**

Mode in reference scenario (2011)	**Share of each mode (all its trips) in trips targeted for this scenario (%)**	**Share of those trips by mode in targeted early adopter shared mobility scenario**		
		Shared Taxi (%)	Taxi-Bus (%)	Feeder service (%)
Taxi	10.0	56.5	39.7	3.8
Bus	77.3	0.0	82.4	17.6
Bus + high capacity public transport	12.7	0.0	95.8	4.2
Total trip mode share for shared mobility scenario		5.7	79.8	14.5

An interesting perspective of the impacts of this baseline adoption is obtained through the average of travel time ratios between this scenario (for Taxi-Buses) and the reference case (for buses), equal to 0.42, meaning that the travel time in this new form of demand-responsive public transport will typically be less than half that of the most similar current situation. The main reason for this improvement is that there are no transfers, and to a smaller extent there is less congestion on the network. Some further impact analysis is developed after presentation of the modal shares in the three successive steps of this adoption pathway.

In a second scenario along this path, we considered stronger adoption of shared mobility services with the same idea of targeted adoption for other early adopters whose use-cases and trips could benefit from the switch, aiming at twice the number of transferred trips from the previous scenario. In this scenario, and following the same ranking of users as before, we replaced very long walking trips (greater than 3 km) and trips taken by car where drivers had to pay for parking at the destination, in addition to the trips replaced in the previous scenario.

Returning to Table 6, by showing the successive user groups in terms of propensity to consider shifting to shared mobility modes, it can be seen that whereas the baseline adoption scenario (25.88% ~ 26% of all trips) is fully "loaded" with trips from classes 1 and 2, the double baseline adoption scenario fully uses class 3 and 4 (another 7.66%). However, the double baseline adoption scenario still requires another 18.46% (52% - 25.88% - 7.66%) of all trips from class 5, that is 18.46% out of a group of 45.10% of all trips, or 40% of this group of trips in which parking had to be paid for and had stays shorter than three hours.

These shifts seem quite natural: long walking trips (4.5% of total walking trips are longer than 3 km) are mostly done for lack of a suitable public transport service and so would very likely opt for the new Taxi-Buses or Shared Taxis; and we could expect that a good proportion of car trips involving the need to pay for parking are also likely amenable to change to the shared modes given the high quality and low prices that are expected there.

To help shift from cars to shared modes in a real situation, public authorities must calibrate interventions, both from the side of disincentives for using private cars (by reducing parking supply, increasing price or reducing maximum allowed duration) and from the side of quality of supply of the new shared modes. In this report, the double (and then the triple) baseline adoption scenario are presented as examples of orders of magnitude of modal shifts, without any need to be very specific about the type and intensity of the measures necessary to reach the levels of those modal shifts used in the modelling.

Table 14 shows that it is necessary for just under 50% of private car trips to adopt shared modes in order to double the fraction of total trips adopting the shared mobility options in relation to the baseline adoption scenario, as slightly more than half (51.3%) of those trips by private car will remain in that mode. This wider set of trips accounts for 52% of all LMA trips and 50% of the overall passenger.kilometres travelled in the LMA. This is designated “double baseline adoption” scenario.

Table 14. **Targeted early adopter scenario: Double baseline adoption scenario**

Mode in reference scenario (2011)	Share of each mode in trips targeted for this scenario (%)	Share of those trips by mode in targeted early adopter shared mobility scenario				Remaining share in each mode of those not yet adapted to shared mobility scenario (%)
		Walking (%)	Shared Taxi (%)	Taxi-Bus (%)	Feeder service (%)	
Private car (PC)	43.20	0.00	63.80	26.10	10.10	51.3
Motorcycle	1.00	0.00	48.90	46.50	4.50	49.0
Taxi	5.00	0.00	56.50	39.70	3.80	0.0
Bus	38.60	0.00	0.00	82.40	17.60	0.0
Walk	4.50	7.60	0.00	74.50	17.90	87.7
High capacity public transport (metro, rail, ferry)	1.10	0.00	0.00	7.20	92.80	91.5
PC + high capacity public transport	0.30	0.00	0.00	32.00	68.00	83.0
Bus + high capacity public transport	6.30	0.00	0.00	95.80	4.20	0.0
Total trip mode share for shared mobility scenario		0.30	30.80	55.10	13.70	-

Finally, the third targeted early adopter pathway, aiming at three times the number of trips of the baseline adoption scenario, considered for mode change all of the trips taken in the entire LMA except those by car drivers who had free parking at their destination, and those made on motorcycle. This scenario recognises that these travellers might be most resistant to giving up the convenience and (relatively) low cost of personal mobility that they currently experience. Depending on specific arrangements in place for the parking supply to those car drivers (some of them park in private spaces while other use public parking garages and have their subscriptions paid by the employer), incentives for the mode shift towards shared mobility solutions will be different. Specific consideration of the trips by motorcycles would also be required, particularly if their market share grows as a reaction to the limitations on use of private cars.

Table 15. **Targeted early adopter scenario: Triple baseline adoption scenario**

Mode in reference scenario (2011)	Share of trips in each mode targeted for this scenario (%)	Share of those trips by mode in targeted early adopter shared mobility scenario				Remaining share in each mode of those not yet adapted to shared mobility scenario (%)
		Walking (%)	Shared Taxi (%)	Taxi-Bus (%)	Feeder service (%)	
Private car (PC)	55.4	0.0	61.5	28.7	9.7	6.3
Motorcycle	1.2	0.0	49.9	45.3	4.9	10.8
Taxi	3.3	0.0	56.5	39.7	3.8	0.0
Bus	25.7	0.0	0.0	82.4	17.6	0.0
Walk	6.5	4.4	0.0	78.2	17.4	73.5
High capacity public transport (metro, rail, ferry)	2.6	0.0	0.0	6.2	93.8	70.7
PC + high capacity public transport	1.1	0.0	0.0	31.5	68.5	0.0
Bus + high capacity public transport	4.2	0.0	0.0	95.8	4.2	0.0
Total trip mode share for shared mobility scenario		0.4	54.9	72.8	21.9	-

The trips considered for mode change in this scenario account for 78% of all trips taken within the LMA and 82% of the overall passenger.kilometres travelled in the LMA. This is designated "triple baseline adoption" scenario.

Table 16 presents a few synthetic indicators of the mobility performance in each of these targeted early adopter scenarios.

Table 16. **Synthetic indicators for gradual adoption of shared mobility**

Indicator	Reference scenario 2011 (%)	Baseline adoption scenario (%)	Double baseline adoption scenario (%)	Triple baseline adoption scenario (%)
% of PKM in individual modes (PC or motorbike)	67.0	55.1	27.4	5.2
VKM (weighted) variation relative to ref. case	-	-2.6	-26.5	-33.1
CO_2 emissions variation relative to ref. case	-	-15.3	-36.9	-47.9

Note: PC = Private car; PKM = passenger.kilometre; VKM = vehicle.kilometre.

Taking these successive adoption scenarios as part of a transition pathway, it is possible to produce some conclusions:

- In the baseline adoption scenario, as shown above, there is a considerable reduction of travel times for bus users when they convert to Taxi-Buses, but that does not seem to be enough as this scenario has virtually no impact on traffic volumes and achieves a small reduction of CO_2 emissions (15.3%).

  There is an apparent reduction of the percentage of passenger.kilometres (PKM) done in individual modes, but this is associated with the overall increase of PKM (due to shift from long walks to Taxi-Buses) and to the longer routes taken by Shared Taxis in comparison with single user taxis, while the absolute number of PKM in those individual modes stays the same.

  As such, while this configuration may still have some political cost associated with imposing changes (in this case from scheduled buses to Taxi-Buses and from single user taxis to Shared Taxis) it seems to bring no visible benefits to the main social indicators and so should be seen as a less interesting first step in the adoption pathway.

- The double baseline adoption scenario has some political costs for acceptance, as it introduces not only new services but actually significant restrictions on parking. If it comes accompanied by a good supply of Taxi-Bus and Shared Taxi services this may be considered as a socially justifiable measure to reduce congestion and emissions. The simulation results are quite encouraging in this scenario, as some rather visible benefits are already to be expected: Passenger.kilometres in individual transport modes are half those in the baseline adoption scenario, but more importantly traffic volumes are reduced by 26.5% (no congestion remaining) and CO_2 emissions are reduced by 37%.

- The triple baseline adoption scenario is much closer to the full deployment in terms of the penetration of shared mobility solutions and has correspondingly good performance indicators, both in terms of traffic volumes (33% reduction from the reference case) and CO_2 emissions (just above half of the reference case). But getting there requires political decisions that are only acceptable when there is great public recognition of the merits of this kind of solution, which is only to be expected after the double baseline adoption has shown its merits and the intention to proceed along that path has been announced.

In synthesis, this analysis shows that it is possible to have a phased implementation of an urban mobility system based on shared mobility solutions, but also that careful analysis is necessary before such a process starts: in this example, the results of a three-phase process showed that there is a minimum intensity of publicly perceptible change in the first step to achieve credibility. Because of that requirement, a two-phase process would be the best option as the first phase shown here would deliver very limited results. But transition processes must always be carefully designed for each city; this is only presented as an example of the need to deliver perceptible results already in the first phase of implementation.

The scenarios described here have far-reaching impacts beyond those linked specifically to transport and mobility. They involve significantly different lifestyle configurations than what people experience at present and will give rise to new opportunities and constraints for many commercial and public actors, including many that do not even exist today. Cities themselves will look quite different – especially as concerns the streetscape and the quantity and quality of public space. Managing the transition described in this report will therefore require addressing a broader range of considerations and preparations beyond the strict transport-related measures described above.

When looking at how these early adopter scenarios might play out in real life, it is important to understand that early experience with the new services will likely influence later adoption rates (or even whether the services become commercially viable). If early adopters are disappointed as they face long waiting times, long travel times and low reliability, then it is likely that their experience will slow or stop further adoption by new users. Conversely, if early adopters are satisfied and report very low response times and high reliability, uptake will likely accelerate based on those experiences. This suggests that early implementation of shared mobility solutions should be centred on use cases or in contexts where extremely high quality of service – especially compared to existing options – is virtually guaranteed. It also suggests that if public authorities are invested in ensuring the broader uptake of these services, they should implement policies that would incentivise their use.

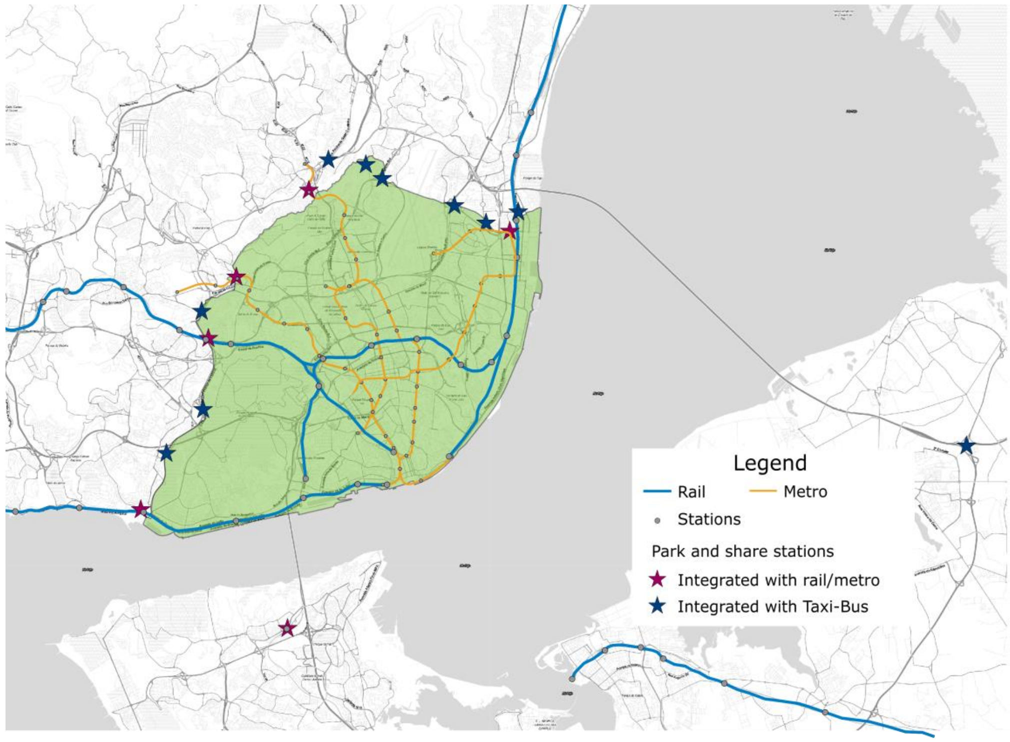
Alternative policy scenario: Access restrictions of private cars to the city of Lisbon

An alternative scenario was also developed, which considered applying a low emission zone within the city (municipality) of Lisbon, with constraints on parking and traffic circulation within the city, leading to adoption within the city of a similar behaviour to that described in the double baseline adoption scenario. (For this exercise, we assume that outside of the Lisbon city centre the current [2011] situation still holds).

Additionally, trips by non-residents of Lisbon currently performed in private car or motorcycle and entering Lisbon are constrained, possibly depending on their licence plate number. We simulated two scenarios: the first where there would be an access ban for one weekday, the second where there would be an access ban for three weekdays.

For those whom entry into the city by private car or motorcycle is not allowed, those trips are served by a group of park and rideshare stations where private cars and motorbikes can be parked (see Figure 15). People that use this solution travel to their final destination either by Taxi-Bus services or via metro or rail (six of the stations in Figure 15 have integration with rail and metro). Mobility between other areas of the metropolitan area was kept the same as in the reference scenario.

Figure 15. **City of Lisbon cordon and park share locations**



Source: ITF, Map tiles by QGIS.

Table 17 presents some of this scheme's performance results for the city. The two first columns serve as the framework, the first one related to the reference case and the second related to the full adoption of the shared mobility solutions, as presented in Chapter 2. The two rightmost columns show the values to be expected with - in both cases - adoption within the city of the measures corresponding to the double baseline adoption scenario presented in the previous section. The fourth column shows one day of prohibition of entry of private cars of non-residents into the city and the fifth column three days of such prohibition.

Table 17. **Performance indicators for the scenarios of action only by the Lisbon municipality**

Indicator	Reference scenario 2011	Full adaption of shared mobility	Results for double baseline adoption scenario +1 day access ban	Results for triple baseline adoption scenario +3 day access ban
% of PKM in individual modes (PC or motorbike)	67.0	0	39.2	16.1
% of VKM (weighted) variation relative to ref. case	-	-50.8	-17.8	-29.9
% of CO_2 emissions variation relative to ref. case	-	-63.5	-21.7	-37.2

As defined above, the double baseline adoption scenario includes the following measures:

- shared mobility services replace all bus services with Taxi-Bus or feeder services
- Shared Taxi services replace all single user taxi services
- trips taken by car where about 40% of the drivers that had to pay for parking at the destination are transferred to Shared Taxis or Taxi-Buses
- very long walking trips (greater than 3 km) are supposed to also get transferred to Taxi-Buses.

While it is obvious that the traffic and emissions indicators under this geographically delimited scheme are not as good as under the full adoption of the shared mobility solutions across the LMA, the measures considered here can produce quite interesting results for the city.

In fact, in the first of the scenarios tested here (one-day car access ban for non-residents), the percentage of PKM from individual modes is reduced to 60% (39%/67%) of the reference case, traffic volumes are reduced by 18% (very little congestion left) and CO_2 emissions by 22%.

The second scenario tested, and possible second phase in this process (three-day car access ban for non-residents) naturally achieves stronger results: the percentage of PKM in individual modes goes down to 24% (16% / 67%) of the reference case, while traffic volumes and CO_2 emissions reduce by 30% and 37% respectively.

These results indicate clearly that a phased approach is possible and can be successful in this scenario of a geographically delimited approach in which the Lisbon municipality decides to move forward by itself without being accompanied by the other municipalities in the LMA.

Market structure scenarios

Two scenarios with different market structures are run as an alternative to the full implementation of shared mobility solutions in the LMA under a single monopolistic dispatcher, where more than one dispatcher (operator) is available in the market and there is some market differentiation.

For this analysis three different market players (dispatchers) were designed, based on preference of clients. These dispatchers have the following features:

- Dispatcher 1: Runs (controls) Taxi-Bus services in the LMA as well as a fleet of Shared Taxis which are called upon in the case that a decision to upgrade a Taxi-Bus client is made. The lexicographical choice of Taxi-Bus or feeder services is used to trigger requests to this dispatcher. This operator is similar to the central dispatcher used in previous exercises, but just with a smaller market size (71% of the market).

- Dispatcher 2: Runs (controls) conventional Shared Taxi services in the LMA. This dispatcher gets the clients that have selected Shared Taxi in the lexicographical procedure (25.4% of the shared mobility market).

- Dispatcher 3: Runs (controls) higher standard Shared Taxi services in the LMA with a vehicle capacity of 3 and more demanding specifications in terms of waiting time and time loss tolerance (-50%). This dispatcher gets clients randomly selected from the 30% of car users in the higher income group (larger than the 75th percentile of incomes), with no public transport pass. The clients represent 3.4% of the number of trips and 4.1% of the passenger.kilometres.

The obtained market segments by corridor are presented in Table 18. In this scenario, even if the transport services available are exactly the same as under the full adoption of shared mobility as described in Chapter 2, there is a considerable loss of efficiency resulting from the three-way split of the market. The reduction of traffic volumes from the reference case is only 26.6% instead of 51%, and the reduction of CO_2 emissions is 31.3% instead of 64%. We did not calculate the breakeven prices for each of the supply segments in this scenario but all of them would inevitably be much less attractive than those computed for the full adoption scenario.

This happens because of the loss of integration in the supply of Shared Taxis (separate operators for the original clients and for the upgraded clients) so that in many cases, a Shared Taxi would be available in very good conditions of time and place to serve a client. But it was managed by a different dispatcher than the one selected by that client, and as a consequence, another vehicle, with a longer route and very likely with lower occupancy, would need to be mobilised.

Table 18. **Performance indicators for a scenario with three dispatchers**

Indicator	Reference scenario 2011	Full adaption of shared mobility with one dispatcher	Full adaption of shared mobility with three dispatchers
% of PKM in individual modes (PC or motorbike)	67.0	0	0
% of VKM (weighted) variation relative to ref. case	-	-50.8	-26.6
% of CO_2 emissions variation relative to ref. case	-	-63.5	-31.3

The question of how many operators of the Shared Taxis or Taxi-Buses was found to be non-critical. The authority must specify minimum (or compulsory) standards for the vehicles to be used, as well as the necessary qualifications for the drivers, and the requirements for data exchange between the vehicles and the dispatcher. Because of the dynamic assignment of new clients, vehicles must follow the route specified by the dispatcher, as well as return to the depot assigned by the dispatcher when they end a trip and have no assigned clients or no clients on board. The way ownership of the fleet is distributed by the number of operators is of minor importance in this context.

Take for example a situation with one dispatcher and multiple competing operators, each with some differentiation of its offer (e.g. vehicle brand, price, loyalty programs), a client would still use the app linked to the dispatcher and would get information on the "best" offers available for the requested ride, indicating for each offer the operator brand, the estimated waiting time, the estimated arrival time at destination, and the estimated price. The client would then choose which of these offers is preferred and the dispatcher would issue the order to the corresponding operator.

It is important to consider encouraging a healthy competitive marketplace for such services, which is why such a solution could, while delivering the benefits of competition between operators, still retain the efficiency gains of having a single dispatch function managing real-time information on available rides.

Whatever the market structure put into place, it will be important to manage empty kilometres made by Shared Taxis as they roam to best position themselves in anticipation of future requests.

In the design concept presented here, the dispatcher centralises real-time information about the location and occupancy of Shared Taxis. Predictive decision-making algorithms using historical use data informs the dispatching function as it seeks to adapt to demand patterns throughout the day. This task plays a key role in reducing vehicle.kilometres made by empty Shared Taxis. Centralising empty-kilometre reduction through a single dispatcher reduces inefficiencies arising from guess-inspired roaming.

From the perspective of overall system efficiency, strict adherence to dispatch routing is necessary. Dispatch compliance may be difficult to enforce where there are multiple operators, but options such as differentiated tariffs set by relevant authorities could limit such a practice.

Alternatively, we also assessed the impact of remaining with a single operator but considering a new class of service – exclusive occupancy of a Shared Taxi, by specific request of the client. In the model we assumed these are the same clients that would use Dispatcher 3 in the previous example (3.4% of the trips, 4.1% of the PKM). Table 19 presents the corresponding results.

Table 19. **Performance indicators for a scenario with a single dispatcher and the possibility of exclusive occupancy in Shared Taxi services**

	Reference scenario 2011	Full adoption of shared mobility	Shared services (Shared Taxi with single use)
% of PKM in individual modes (Shared Taxi alone)	67.0	0	4.1
VKM (weighted) variation relative to ref. case	-	-50.8	-43.9
CO_2 emissions variation relative to ref. case	-	-63.5	-56.6

Allowing the provision of exclusive occupancy of taxi services responds to a market segment that inevitably will exist and can be very important (at least in the introductory stage of shared mobility) to encourage general acceptance. Moreover, it would be very difficult to enforce such a prohibition, since in significant parts of their duty Shared Taxis only carry one passenger. But the impacts in terms of traffic volumes and CO_2 emissions (in relation to no possibility of exclusive services) are not negligible: allowing exclusive occupancy service in 3.4% of the trips, (representing 4.1% of the PKM) cuts reductions of traffic volumes and CO_2 emissions by 6.9% (a factor of 1.7 to that 4.1%).

The price for this kind of service must naturally be higher per passenger.kilometre to compensate the operator for the potential loss of revenue from other passengers that might share part of the ride. This amplified impact on efficiency, however, leads to the recommendation that authorities calibrate the price differential between this and the regular Shared Taxi service so that its demand stays at a modest level.

These two tests give two clear indications. First, the loss of efficiency associated with a split of the dispatch function across multiple providers (three in this test) is considerable. While there could be some advantages in terms of competitive innovation in services provided, these results suggest that system efficiency is best delivered through a single dispatch function, possibly a monopoly regulated by a public authority under a tendered concession contract for some years. Second, allowing exclusive occupancy of Shared Taxis responds to a natural demand but it must be managed through the price differential to ensure that overall impacts on the system-wide efficiency are not too high.

4. Can shared mobility serve people with special mobility needs?

One important aspect in any implementation of shared mobility systems will be the extent to which they can provide equal or better mobility outcomes for *all* people, not just for one portion of the population. In particular, if these systems cannot provide good access for those with physical, sensory or cognitive impairments – impairments that many in the general population will experience at specific periods or more systematically as they age – then it is difficult to see how these systems will gain broad support, especially from the governments that will likely retain regulatory oversight and licensing authority over these services. ITF (2016b) proposed a framework to value the social and economic benefits of improved access, including time savings, greater convenience, more employment opportunities and savings across the social care and health sectors. International evidence presented in that report also points to the potential of accessible transport systems to generate large economic benefits. It is also important from a human perspective; can these services provides better outcomes for those who face difficulty walking or using cars, buses, trains and metros today? If so, then their deployment should become a priority.

This section presents a first simulation of how demand-responsive, shared mobility solutions could be used to address the access and mobility needs of people with some form of significantly reduced mobility. For the purposes of this simulation, we have focused on transport of individuals using wheelchairs or those with reduced mobility due to chronic or temporary disabilities or special mobility requirements. Given the exploratory nature of this exercise and the lack of specific data, the simulation treats all these cases in a similar manner:

- All are served by door-to-door Shared Taxis (no Taxi-Bus services).
- All are served with a specially adapted vehicle with a ramp (or a lift), a wider door (on the side or on the back) and a safe place to anchor a wheelchair (or a baby pram or larger shopping cart), along the lines required by the US ADA (Americans with Disabilities Act) or other analogous national standards. The same kind of vehicle as for the general population is used as a basis for the accessible service. These vehicles are 8-seater minivans with accessible doors and capacity for five passengers. The vehicles adapted for service to this segment also perform service to passengers without special needs in the same conditions as the non-adapted vehicles.
- Boarding and alighting time for each of these passengers is extended by 30 seconds on average in relation to that adopted for the general public.

These are rather generic attributes and the concept is rather simple: include people with special mobility needs in the shared rides scheme that are made available to the whole population. Given the nature of the exercise and the absence of specific information on the distribution of these special needs across the population represented in the mobility databases (and consequently in our synthesis population), we made a set of simplified assumptions:

- We assumed that the percentage of people with special mobility needs was 10%. Whether this value is above or below the real situation in any particular city will depend not only on the characteristics of its population but also on what may be understood as "with special needs". We expect that it is sufficiently realistic to be accepted as approximately right for the targeted population we are proposing in the simulation, i.e. wheelchair users and individuals with significantly reduced mobility.
- The shared mobility simulation approach employed in this case includes Shared Taxis, in addition to other choices including Taxi-Buses, walking and metro or regional rail-based public transport.

Whereas all these choices are available to the rest of the population, our scenario calls for the use of Shared Taxis only by those with accessibility needs. They therefore represent a disproportionate share of Shared Taxi users and account for about 35% of all Shared Taxi trips.

- The allocation of the 10% of travellers with accessibility needs in our synthesis population was conditioned by several other variables for which we had information:
    - People with more than four trips per day were excluded from this segment.
    - The probability of having special mobility needs was indexed to age: people under the age of 55 were allocated a weight of 1, those between 56 and 75 a weight of 2, and those above 76 a weight of 4.
    - People driving their own car are ranked after all the others.
    - We went through the whole synthesis population and sorted according to the resulting combined weight of these different aspects. Once the percentage of the population to be considered with special needs is defined by the user at the beginning of the simulation, those in the high end of the list down to the corresponding number of people are labelled as "with special needs" and those below as "no special needs".

Since the beginning of the ITF work on shared mobility solutions critical importance was given to the issue of quick availability of Shared Taxis as specified through the maximum allowed waiting time and total lost time (waiting + detour times). This was motivated by the need to get strong acceptance of the new solutions by current car drivers and thus achieve a decisive modal shift. This aspect of quality of service naturally has an impact on the cost of provision of that service, and after some research it was found that those maximum times should vary with the trip length.

Given the much higher costs of accessible vehicles, a critical question in designing these services is related to the fleet: what fraction of the whole fleet should be dedicated to accessible vehicles? This has repercussions not only on costs but also on maximum waiting times for the people with special mobility needs.

Many cities around the world strive to make all taxis and public transport services accessible to people with special mobility needs. In other instances, cities provide some form of paratransit service especially targeting citizens with accessibility needs that cannot be readily met by taxis or by public transport. Such services are often provided in a demand-responsive manner, but with long response time, typically at least one hour but sometimes even one day, much higher than the headways of scheduled public transport or response times of regular ride services. The reasons for this lower quality of service are associated with the separate, dedicated provision of that service to a relatively small part of the overall demand for public transport (and to a much lesser extent, to the additional cost of the adapted vehicles).

This work explores how much shorter that response time could be, leveraging potential scale effects of a Shared Taxi fleet in a system configuration where vehicles are shared by people with special accessibility requirements and those who are fully mobile.

In our earlier studies, maximum acceptable waiting times (as well as the total lost time = waiting time + detour time) were found to be preferably dependent on trip length in our other work on shared mobility systems. Because of this, the exploration of "How much shorter could the response time be?" was characterised in terms of the ratio between the maximum acceptable waiting times in the segments of people with reduced mobility and with full mobility, for various ranges of trip length.

It is worthwhile thinking a bit more about those additional costs: if the maximum acceptable waiting times for people with and without special mobility are the same, many adapted vehicles will be necessary. But as the ratio between these maxima grows (say up to a ratio of 2.0), the number of adapted vehicles necessary will diminish (reducing capital costs). But serving those passengers with special needs may bring longer empty rides and/or may force them to longer waiting times. The value of the additional waiting time imposed on those passengers must also be taken into consideration.

So, we ran the simulation model for a number of different situations regarding fleet composition:

- No adapted fleet (as if there were no passengers with special mobility needs) - this is the reference case for computation of the cost differentials.
- All adapted fleet - this is the maximum flexibility case, offering equal quality of service to all clients. It also has the maximum capital cost, but possibly not the highest operating cost.
- Partly adapted fleet – this includes three different ratios between the maximum acceptable waiting times (RMAWT) for the two population segments (respectively 1.0; 1.5; 2.0). The ratio for total lost (waiting and detour) times would be the same.

For each of these ratios we computed three cost components:

- Capital costs (amortisation + maintenance + insurance) of the Shared Taxi fleet.
- Operating costs of the Shared Taxi fleet.
- Value of time lost waiting by the people with special mobility needs (considering only the time above the maximum allowed for the people without special mobility needs): The value of time adopted was EUR 0.05 per minute, similar to the typical values calibrated in other studies in the LMA (Eiró and Martinez, 2014).

For the cost calculations, the assumptions about the accessible minivans used as Shared Taxis were the following:

- additional purchase price 40% above the normal purchase price of the same base vehicle (as used for the non-accessible Shared Taxis)
- fuel costs 10% above those for the non-accessible minivans
- maintenance and insurance costs in the same percentage of the purchase cost
- amortisation period same as for non-accessible minivans.

As in earlier studies, the simulation is run with a Shared Taxi "generated" in the system when a request cannot be satisfied with the already available supply and respecting the maximum waiting time, with the only difference that, depending on the case being run, the type of vehicle may be generic or accessible:

- **Scenario A:** When there is no accessible fleet, no clients are considered as having special mobility needs and all generated vehicles are generic (non-accessible).
- **Scenario B:** When all the fleet is accessible, the generated vehicles are accessible irrespective of the mobility needs of the client triggering that generation.
- **Scenario C-E:** In the cases of partially accessible fleet, when the client making that request has special mobility needs, an accessible vehicle is generated; otherwise a generic vehicle is generated. Thus, in this group of three cases, the fraction of accessible vehicles in relation to the whole fleet of Shared Taxis, and the overall size of the Shared Taxi fleet, are a function of the specifications regarding the maximum acceptable waiting and total lost time of the clients with the special needs in relation to the general population.

As mentioned above, the first runs of the simulation had the purpose of making the basic decision regarding fleet composition, based on the costs and service quality (maximum waiting times) associated with each option. To facilitate perception of these results in a meaningful scale, the unit of all costs is EUR per passenger.kilometre of the shortest route possible for every trip.

For reasons of computation time, this initial analysis regarding the composition of the fleet covered only the territory of Lisbon city centre, with a much stronger concentration of elderly people. The results for each of the cost components indicated are shown in Table 20.

Table 20. **Characterisation of tested scenarios for accessible Shared Taxi services**

Fleet scenario	A	B	C	D	E
	No accessible fleet	All accessible fleet	Partly accessible fleet: RMAWT 1.0	Partly accessible fleet: RMAWT 1.5	Partly accessible fleet: RMAWT 2.0
Fleet size (Reg /Adapt / Tot)	3997 / 0/ 3997	0/4190/4190	1541/2811/4352	1653/2499/4152	1677/2358/4035
Capital cost	0.122	0.133	0.130	0.128	0.127
Operating cost	0.487	0.533	0.519	0.512	0.509
Value of extra waiting time	0	0	0	0.006	0.009
Sum of the two money costs	0.609	0.666	0.649	0.640	0.636
Sum of the three money costs	0.609	0.666	0.649	0.646	0.644

Note: Table calculates EUR per vehicle.kilometre, shortest route.
RMAWT=ratios between the maximum acceptable waiting times.

From these results, it is possible to see that the lowest cost option for delivering accessible services is scenario E which costs EUR 0.027 more than the no accessible vehicle scenario – or only 4.4% more. This scenario, however, implies that people requiring accessible Shared Taxis wait up to twice the maximum acceptable waiting time as those with no special mobility needs and requires that 58.4% of the total Shared Taxi fleet be accessible (2 358 out of 4 035 vehicles).

Having a wholly adapted fleet (scenario B) is not only more flexible to operate, particularly if considering an ageing population, but more equitable. And the additional costs implied in relation to the reference case (scenario A) is EUR 0.057, i.e. a 9.3% cost increase. The cost differential from comparing scenario B to the lowest cost scenario (E) is only EUR 0.030 (4.7%). But taking into account the value of extra time lost by those clients, the difference is only EUR 0.22, i.e. 3.4% of that lowest cost.

In synthesis, the lowest additional money cost of providing accessible service to this segment is EUR 0.027 with solution E. Providing a fully accessible service costs another EUR 0.030. From the total EUR 0.057 = 9.3% cost increase associated with full service (scenarios A-B), roughly half is associated with providing accessible service in the first place service, and another half for extending that service to the whole of the fleet.

Based on these findings, the rest of our analysis concerns scenario B – the scenario where every Shared Taxi deployed is fully accessible. Even for this relatively more expensive service, the final delivered service is still much less expensive than the current price of a single-user taxi, and in fact lower than the current public transport price (see below).

Scenario B is also much more compatible with transition arrangements in the case of a gradual deployment since the fleet is homogeneous. In the case of a partly accessible fleet, and for a situation in which only a share of overall trips is served by these modes (e.g. as described in the Chapter 3), the resulting percentages of accessible vehicles would have to be higher than here to get to similar service quality. This is because the quality of service to people with special mobility needs depends essentially on the absolute number of Shared Taxis deployed.

Costs and their impact on breakeven prices

Any political choices about provision of mobility solutions for people with reduced mobility will necessarily consider the quality of service provided, the costs for providing that service and the fundamental right for equal access. A second order decision will then have to be made about what part of those costs is supported by the direct beneficiary (the travelling citizen) and what part is borne by society.

Despite the exploratory nature of this work, it is useful to include a breakeven price analysis similar to what has been done in our other reports on shared mobility solutions. As in earlier ITF reports, these breakeven prices are calculated as 25% above the full capital and operating costs, so as to cover back-office costs and profits.

As outlined earlier, wheelchair accessible vehicles cost more in capital and operations, and may experience slightly longer boarding and alighting times. For these two reasons, delivering a more accessible service costs a bit more than to a fully able population. But having the same fleet serving both segments also benefits the clients without special mobility needs as the additional sharing allows a reduction of the waiting times and of the prices per passenger.kilometre (PKM).

Following the results of the analysis about the composition of the Shared Taxi fleet (covering only the city) the exercise for the breakeven prices was done both for the city and for the LMA. We calculated the breakeven prices for scenarios A and B – that is the breakeven price per PKM for Shared Taxis with no accessibility provisions to a fully accessible Shared Taxi fleet. As usual, these breakeven prices are presented as a percentage of the current equivalent taxi price per PKM. For the case of the city, the value for scenario A - all citizens considered as fully able, all regular minivans – is 33.0%. For scenario B - 10% of the citizens considered as having special mobility needs (equivalent to 35% of taxi trips), all accessible minivans – the value is 36.1%.

The price in scenario B is only 9.5% above that of scenario A, which seems a relatively small differential. The main reasons for the quite small increment in the equivalent price per PKM in spite of the 40% higher capital costs and 10% fuel costs of the adapted vehicles, are the large distances run each day by these shared vehicles and the relatively large part of the costs corresponding to labour, which we assumed would not change. And the breakeven price differential per PKM (9.5%) is a bit different from the cost differential per vehicle.kilometre (9.3%) because the average occupation of the Shared Taxis are also a bit different in the two scenarios.

For the case of the LMA, the breakeven prices per PKM are a bit lower than for the city, at 30.5% of the current equivalent taxi price per PKM for scenario A – all citizens considered as fully able, and 35.5% for scenario B - 10% of the citizens considered as having special mobility needs, all Shared Taxis being wheelchair accessible. This price for scenario B is still below the current equivalent price of public transport, at 85% of that price.

In a case of gradual deployment, as long as the size of the Shared Taxi fleet in each phase is decided with a process similar to the one used in this study, those vehicles will still have very intensive use, leading to similar breakeven price levels.

Concluding remarks on using Shared Taxis for inclusive mobility

This is a generic, exploratory exercise aiming to explore the concept of using Shared Taxis as the basis for ensuring accessible services for people with reduced mobility. The results obtained in the simulation in a setting in which all road-based mobility is provided with shared solutions (Shared Taxis and Taxi-Buses) and all Shared Taxis are adapted (according to ADA or other national standard) minivans show this is indeed possible at a very low cost differential relative to standard shared mobility services (and still lower than the current [subsidised] price for public transport). These results are equally valid for the city and for the LMA.

5. Conclusions

This report, dedicated to shared mobility solutions in large urban areas, builds upon previous work in earlier CPB reports on simulations for the city of Lisbon. It addressed several issues, which are outlined below, followed by a brief note about the associated results for each of them.

How do the estimated impacts for the larger Lisbon Metropolitan Area compare with those estimated for Lisbon city?

Application to this wider territory followed essentially the same approach but took advantage of the existence of a network of high capacity public transport services (suburban rail and ferry, and the metro in the city) by the introduction of a new type of service – Taxi-Buses used as feeders to those public transport services – and led to results that were even slightly better than those for the city, in terms of reduction of traffic volumes and emissions as well as of equivalent prices per passenger.kilometre. Three very important co-benefits would be felt across the whole LMA: access to jobs and other public services would become much better and more equitable; a massive release of parking spaces for other uses of public interest would be possible; and, quite interestingly, introducing the feeder buses leads to a considerable increase of the use of high capacity public transport services.

How could a phased deployment of services, supported in each step by specific policy decisions, be organised and what results could be expected at each phase?

A phased pathway was defined, focusing on more acceptable policy measures that could mobilise early adopters, identifying a first phase that could be introduced to deliver very noticeable positive results, and subsequently building on this for the next phases to achieve the full benefits of the shared mobility concept.

An additional scenario was explored, with differentiated implementation of measures in support of shared mobility, in the city of Lisbon but not in the surrounding municipalities. We found that application only in the city of the first effective phase of the pathway (as simulated for the whole LMA), coupled with a scheme of reduced access to the city for private cars of non-residents could deliver significant positive results for the city.

How would different market structure configurations for the dispatcher role impact efficiency?

Two scenarios were run as an alternative to the single dispatcher configuration and all trips open to sharing adopted as the basis. The first scenario was based on three different dispatchers addressing different market segments, for which we found that the losses of efficiency are very high, leading to a recommendation that this function should be a monopoly. Other ways of organising supply with more than one dispatcher might be less damaging than the one tested, but the results suggest that any movement in that direction should be carefully assessed in advance. It could be feasible to design shared mobility services with a single dispatcher and multiple Shared Taxi operators, thus benefiting from competition amongst operators while preserving system-wide dispatching efficiency. In such a case, special care will have to be given to reduce the incidence of empty vehicle.kilometres.

The second scenario invovled with a single dispatcher allowing requests by some clients for exclusive occupancy (i.e. non-shared) service. Since we believe the demand for these services is inevitable but they induce some loss of efficiency, the recommendation is to make it possible but control the price differential to keep the demand volume for this kind of service at a modest level.

How could an efficient scheme providing equitable access for all be designed, thus delivering high-quality accessibility to those with physical and cognitive disabilities?

The analysis initially focused on what should be the percentage of the Shared Taxi fleet composed of such adapted vehicles, looking at the implications of that choice on costs and on waiting times for those passengers. The result was that if the whole fleet of Shared Taxis was composed of adapted minivans, jointly serving all clients with and without special mobility needs, with the same standards for maximum allowed waiting time, the cost increase per passenger.kilometre would be only a little higher than if no service was provided for those clients, but still lower than the current price of public transport. So the recommendation would be that all Shared Taxis are adapted to serve wheelchairs when the program is launched – this also allows more flexibility in the case of gradual deployment.

Globally, the results are very encouraging in the sense that shared mobility solutions can indeed be a powerful catalyst of change for the quality of life in urban areas, including the wider metropolitan agglomerations. It is also relevant that provision of inclusive mobility to all citizens is possible with a very low cost increase (but still at much lower cost levels than those of public transport in the present), thus bringing together significant gains of personal accessibility and of territorial accessibility.

Since all those results were obtained for a configuration with full deployment of the shared mobility solutions (and the corresponding elimination of some of the current supply options), transition paths were explored and we tried to couple political acceptance and visible positive impacts on each step of the process, and found this to be possible. Additionally, different market structures were tested and important lessons learned about the trade-offs between the efficiency possible with a (regulated) monopoly dispatch of these shared mobility services and the diversity of choices and resilience expected from situations with multiple suppliers.

Evidence in favour of starting the process towards adoption of shared mobility solutions in urban agglomerations is now even stronger. Naturally, each case is different and careful planning is necessary, but the main challenges that had been identified for this exercise have all been successfully met and technology is at a stage (and cost) where this can be applied in support for an evolution towards urban agglomerations with much better accessibility and quality of life for all, virtually no congestion, much lower emissions and much lower capital and operational costs.

Finally, it is important to remember that this study should not be seen as an accurate prediction in exact terms of the future of mobility in cities. It is an indicative predictor of the future based on a synthetic population. In reality, all implementation of such possible new mobility scenarios would need to be implemented gradually, following extensive planning and consultation in the cities concerned. On implementation, careful monitoring and attention to user feedback could ensure that any issues be tackled rapidly so as to not affect quality and reputation of the new services.

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Notes

[1] Earlier ITF studies were based on 2010 data for the city of Lisbon, but this report is able to use a new activity-based demand model calibrated with data from surveys done in 2011.

[2] This adaptation is described in detail in the doctoral dissertation of Tomás Eiró (2015), which has developed the current procedure based on activity data collected under the MIT Portugal Program for the LMA.

Transition to Shared Mobility

How large cities can deliver inclusive transport services

This report examines how cities can manage the transition to shared mobility services. It expands on two earlier studies that looked at the citywide impact of replacing private cars with shared services, but did not address the question of implementation. Based again on mobility data for the city of Lisbon, Portugal, this report assesses issues around the scaling up of shared mobility services to the whole of the Metropolitan area and of their stepwise introduction. It also analyses the impacts of these services on the use of existing high-capacity public transport and on access to jobs, schools or health facilities across the whole study area, and explores how shared mobility can improve accessibility for users with impairments.

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