Car-free cities: how to reorganize urban mobility ?

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Short summary

The urgent need to address climate change forces researchers to explore various solutions to reduce the carbon footprint of mobility and transport. Research in this area mainly focuses on electric vehicles and on the increase of public transport modal share. However, to our knowledge the study of car-free cities remains very superficial yet.
In this paper, we propose to simulate urban trips under different scenarios of private car prevalence. The objective is to evaluate the impacts of car suppression on transport, in particular in terms of modal share and travel time. Our results show that for the city of Lyon, most users would not see any travel time increase if private cars were suppressed. The metro and tramway networks would need minimal adaptation, whereas the bus network would need more significant improvements.
Keywords: Car-free city, Network design, Simulation, Transport, Urban mobility

1 Introduction

In Europe, cars account for 60% of CO_2 emissions due to road traffic, that is, 43% of all transport-related emissions (European Parliament, 2023). In order to lower the environmental impact of road transport, two options have been extensively investigated in the literature: the electrification of the fleet of vehicles (Pereirinha et al., 2018), and policies to promote modal shifts toward public transport and active modes (Javaid et al., 2020).
However, even though these two propositions are essential in a transition toward sustainable mobility, the latest IPCC Synthesis Report (IPCC, 2023) highlights the urgency to substantially lower our energy consumption, which requires a more drastic paradigm shift. Along these lines, the International Transportation Forum showed that car-sharing could reduce the need for personal vehicles by 90% in Lisbon and in Lyon, without reducing the level of service (ITF, 2020), (ITF, 2015). (Nieuwenhuijsen & Khreis, 2016) underline the environmental and health benefits that could arise from an intensive reduction of private cars in cities, while emphasizing the need to conduct further research to evaluate the significance of these impacts.
The present article proposes an even more radical approach: the total abandonment of private car for urban mobility, without any decrease in the mobility demand. It is clear that current public transport systems and bike lane networks are not optimized to absorb the extra demand caused by the suppression of personal vehicles, and that walking is not always an option for longer trips. Furthermore, for many people, the car remains the only identified access to employment, culture and social life. Removing it without offering a viable alternative could reinforce inequalities by creating isolation among the most vulnerable populations (Dorantes & Murauskaite-Bull, 2023), (Nieuwenhuijsen & Khreis, 2016). For those reasons, suppressing private cars will require adjustments of public transport systems and bike lane networks. To our knowledge, no research has been conducted to qualify or quantify those adjustments, nor has any network design problem been investigated under the assumption of zero cars.
This study introduces a qualitative analysis of the limits of the current transport network with the objective of suppressing private cars. Daily urban trips are simulated under different scenarios of private car prevalence. We then compare the travel times and modal shares in the different scenarios, and present results for the city of Lyon, France. Further studies on Athens and Amsterdam are ongoing.

2 Methodology

Simulation tool

We work with the agent-based simulation tool MnMS, developed at Licit-Eco7, to model urban trips of a population (Licit-Eco7, 2022).
In MnMS, road traffic is modeled at a macroscopic scale thanks to macroscopic fundamental diagrams (MFD) (Daganzo & Geroliminis, 2008). This approach allows an accurate modeling of congestion and of its propagation, which affect the modal choice of the users. For now, we consider the bike traffic to be free from any congestion. This assumption makes sense in our case because for now in Lyon, with cars allowed, the observed number of cyclists is low enough to allow free flow circulation on bike lanes. When the number of cars decreases, roads with a larger capacity are available for cyclists. The users also have the option to walk from their origin to their destination, without any congestion either.
In the model, there is no constraint on the capacity of public transport yet either, and thus the congestion of buses, tramways and metros is not directly taken into account. The capacity overrun of public transports is assessed during the analysis of the simulation outputs. A further step of this work will include a better understanding of bikes MFD and consideration of public transport capacity constraints.
The network is modeled using a multi-layer network. In our case, we consider layers for cars, buses, tramways, metros, bikes, and an additional transit layer to model walking routes. Each user has access to a set of mobility services and k shortest paths are computed through the corresponding layers. The user then chooses one of the proposed paths with a decision model based on the travel cost. For cars and bikes, the cost consists of a cost per kilometer, plus a cost in time. For public transport, the cost consists of a unitary ticket, a time component and a penalty when transferring. For walking, only the time is taken into account in the cost. In our study, a logit decision model is used where the probability of choosing one path depends on the travel costs of all possible paths. Deterministic and mixed models are also available in this tool.

Definition of the scenarios

We define six scenarios that only differ in the proportion of users having access to a personal vehicle (PV), which ranges from 90 down to 0. In the following, we refer to a scenario with X% of private car access as "scenario X". If a user has access to a car in scenario X, they also have access to a car in all scenarios $Y > X$, so that we can study the evolution of modal choice and travel time at an individual scale.
In each scenario, 70% of users have access to a bike. This proportion is purposefully overestimated for the city of Lyon, because it allows to see a proper choice between public transport (PT) and bike when the cars are removed. All users are considered to have access to public transport and by default, all users can use the transit layer and walk.

3 Results and discussion

In this section, we present the results of the simulation for the city of Lyon. We simulated six scenarios in order to identify a possible car proportion threshold, from which the system either collapses (and travel times skyrocket), or becomes stable. However we do not observe such a breaking point for the city of Lyon: as we show in the following, the evolution of travel times, modal share and capacity overrun for public transport is rather linear throughout the scenarios. Consequently, we focus on comparing the outputs of scenarios 90 and 0.

Evolution of global travel time

First, we analyze the evolution of the travel time distribution, as the proportion of cars decreases. On Figure 1.a, we notice a global flattening of the travel time histogram (the median shifts from around 11 minutes in scenario 90 to around 20 minutes in scenario 0, which represents a 91% increase), but no extreme increase in the proportion of users with "long" travel times (the last decile increases of only 26.5% between scenario 90 and scenario 0, shifting from 34 minutes to 43 minutes).

Table 1 summarizes the mean, median, last quartile and last decile of travel times for each scenario and each mode. For bikes, cars and public transports, the distribution of travel times does not change significantly from one scenario to another (even though the modal share changes, see *Evolution of modal share*). We expected the duration of car trips to shorten due to lower congestion but this is not the case. However, in scenario 90, walking is essentially considered for very short trips (more than 50% of trips were shorter than 3 minutes). That is not the case in scenario 0, where more than 50% of the trips last more than 10 minutes.

Table 1: Mean, median, last quartile and last decile of travel times (min) by scenario and transport mode.

		Mean	Med	Q3	D9
	ALL MODES	**15.75**	**11.41**	**21.81**	**34.04**
90	PV	7.50	6.94	9.83	12.47
	PT	27.79	25.00	35.37	46.85
	BIKE	15.51	14.40	20.36	27.01
	WALK	11.42	2.90	21.13	31.31
	ALL MODES	**17.30**	**13.23**	**24.24**	**36.59**
70	PV	7.34	6.80	9.61	12.18
	PT	28.08	25.19	35.79	47.51
	BIKE	15.48	14.38	20.30	26.91
	WALK	12.49	4.15	23.11	33.38
	ALL MODES	**19.35**	**15.70**	**27.14**	**40.23**
50	PV	7.20	6.67	9.41	11.95
	PT	29.15	26.12	37.49	49.60
	BIKE	15.51	14.42	20.34	26.96
	WALK	14.12	8.28	25.19	36.63

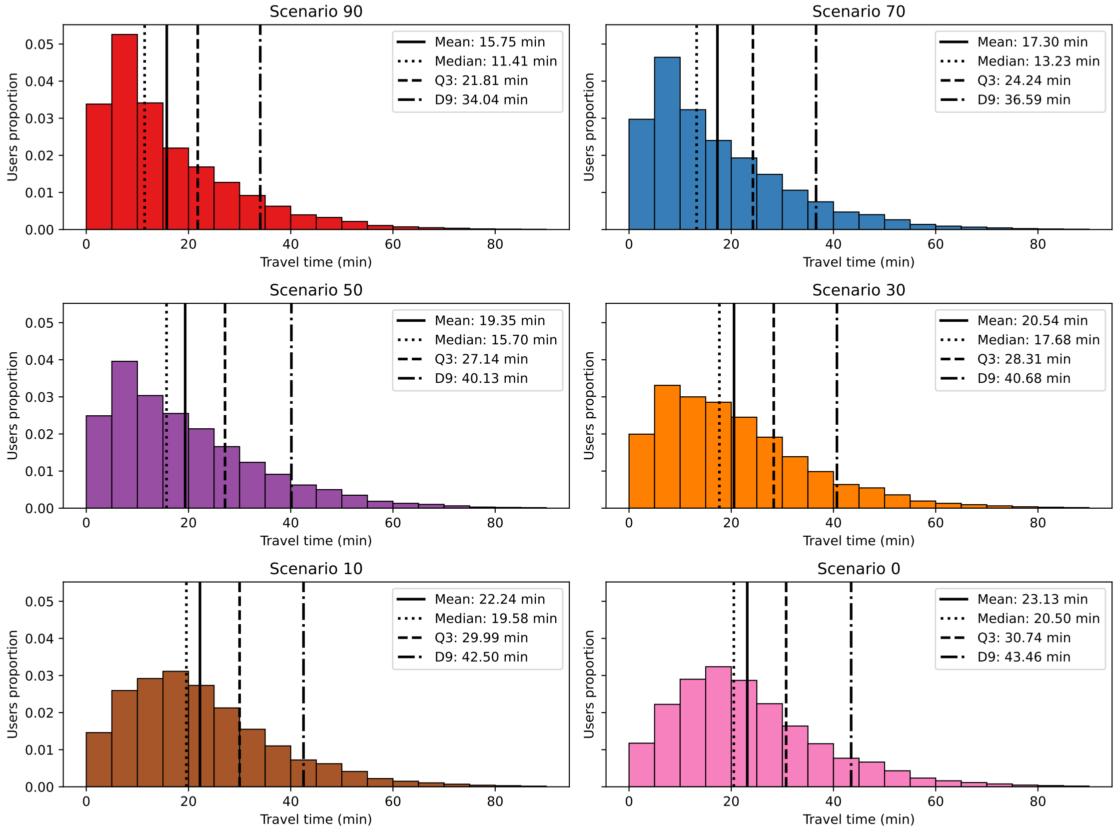
		Mean	Med	Q3	D9
	ALL MODES	**20.54**	**17.68**	**28.31**	**40.68**
30	PV	7.07	6.54	9.23	11.69
	PT	28.41	25.42	36.21	48.21
	BIKE	15.52	14.40	20.34	26.99
	WALK	14.15	8.62	25.02	36.95
	ALL MODES	**22.24**	**19.58**	**29.99**	**42.50**
10	PV	6.91	6.39	9.04	11.38
	PT	28.54	25.52	36.39	48.48
	BIKE	15.53	14.42	20.35	27.00
	WALK	14.89	10.20	25.50	39.33
	ALL MODES	**23.13**	**20.50**	**30.74**	**43.46**
0	PV	-	-	-	-
	PT	28.63	25.59	36.51	48.59
	BIKE	15.51	14.40	20.33	26.98
	WALK	15.23	10.89	25.75	41.25

Evolution of individual travel time

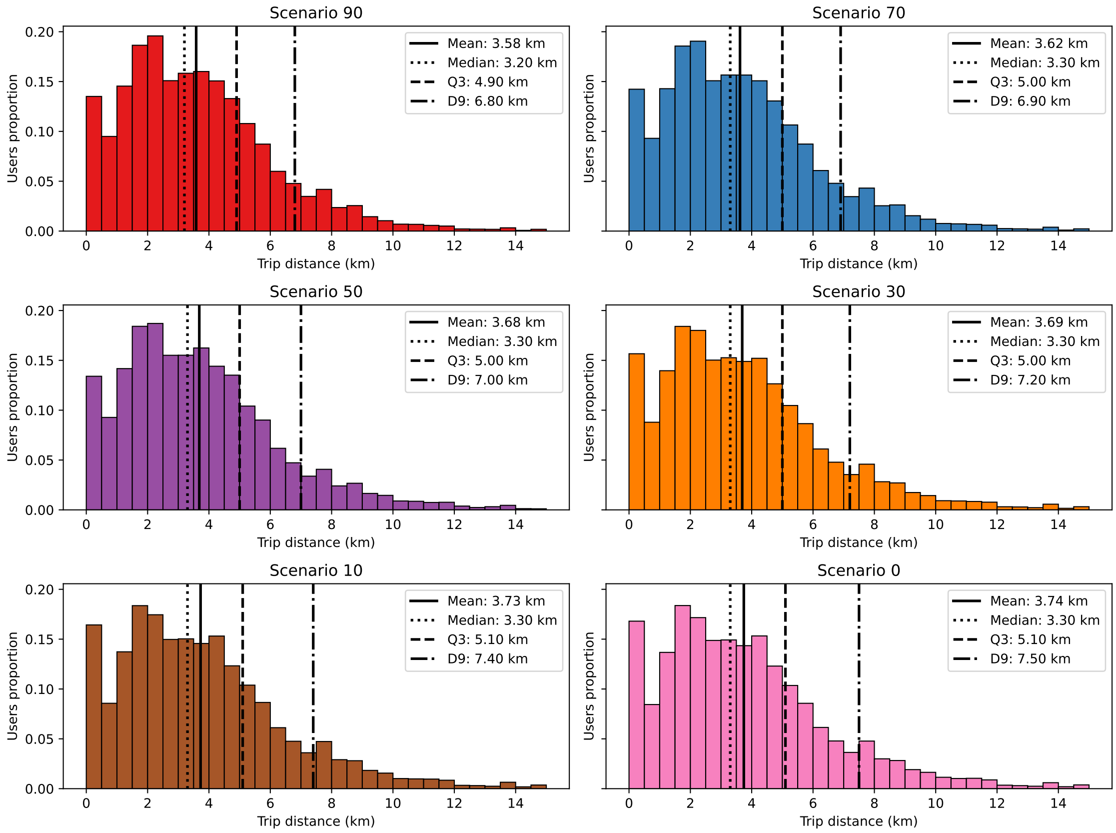
We then compare for each user the travel time difference between scenario 90 and scenario 0. Half of the users reduce or do not change their travel time in scenario 0 with respect to their travel time in scenario 90 (Figure 2). Even though the spared time is usually small (less than 10 minutes, as shown on Figure 2.b), the proportion of users who decrease or do not change their travel time is encouraging in a context of private car reduction.
However, even if travel time increase only concerns 50% of users, it can be serious. 25% of total users see their travel time increase by more than 142% between scenario 90 and scenario 0, which means that their travel time is multiplied by at least 2.4 (Figure 2.a).
To explain this travel time increase, we compare the trips of those users in scenarios 90 and 0. It appears that those users were exclusively using private cars in scenario 90 (this is not surprising since the congestion of bikes lanes and public transport is not simulated, therefore the users who already used those modes in scenario 90 barely change their travel time in further scenarios). 80% of concerned users shift to public transport, 12.5% of them shift to walking and 7.5% shift to cycling.
As shown in Table 2, the trip length does not change significantly for users who replace their car with an active mode. We can thus assume that the travel time difference is caused mainly by the speed difference between cars and active modes. Furthermore, even though we observe a large relative travel time increase when users shift from private car to walking, the concerned trips are relatively short in distance (2.3 km in average, the median of the trip distances being of 3.2 km in scenario 90 and 3.3 km in scenario 0, see Figure 1.b) and therefore remain of a "reasonable" duration.
For users who shift to public transport, several hypothesis can explain the longer travel times:

1. The users live far away from public transport lines and have to walk a long time to find a stop, whereas their private car is available at their origin point;
2. They live along a line that presents a long headway and have to wait for a long time, whereas with a private car this delay does not exist;
3. They have to change lines multiple times because no line goes directly from their origin to their destination, whereas the car trip is direct;
4. The line they have to take might be direct but makes detours, whereas the car trip is straightforward.

Further analysis should be conducted to understand which of these hypothesis apply in the case of Lyon users. Nonetheless, we observe that the trip length average raises from 3.7km in scenario 90 to 4.6km in scenario 0 (Table 2), which is particularly consistent with hypotheses 3 and 4 even though it does not undermine hypotheses 1 and 2.

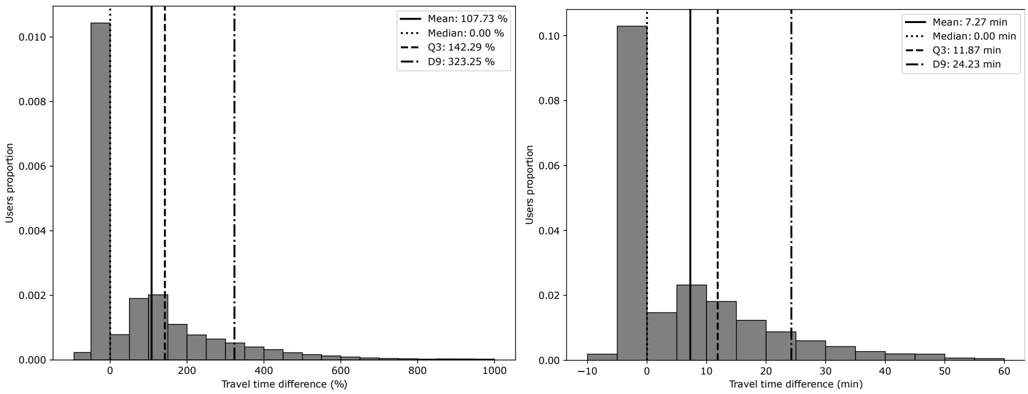


(a) Travel times.



(b) Trip distances.

Figure 1: Distribution of travel times and trip distances by scenario.



(a) Relative travel time difference. **(b)** Absolute travel time difference.

Figure 2: Distribution of relative and absolute travel times difference for each trip between scenarios 90 and 0.

Table 2: Mean distances of trips that gain more than 142% of their travel time from scenario 90 to scenario 0, grouped by chosen transport mode in scenario 0 (all users chose PV in scenario 90). A 142% travel time increase represents the last quartile of travel time difference between scenarios 90 and 0 (Figure 2.a).

	PV → WALK	**PV → BIKE**	**PV → PT**
Number of users with travel time difference ≥ 142% (Fig. 2.a)	13 784	8 750	87 484
Mean trip distance in scenario 90 (km)	2,3	4,6	3,7
Mean trip distance in scenario 0 (km)	2,4	4,6	**4,6 (+0,9)**
Explanation of travel time increase	Slower mode	Slower mode	- PT path is less straightforward - Numerous changes - No PT line near origin/destination - Long headway

Evolution of modal share

Figure 3.b shows the modal share for each scenario. We notice that in every scenario, less than 50% of users who have access to a private car decide to use it. The share of public transport and active modes rises linearly through the scenarios, as shown by the linear tendency curves (dotted lines) on the chart. All the curves have a coefficient of determination $R^2 > 0.98$.

Capacity overrun in public transport

As explained previously, the capacity of public transport vehicles is not a simulation constraint yet. Thus after the simulation we analyze the lines which carry more passengers than they are supposed to. The capacity of public transport is hard to determine precisely because depending on the lines, several models of vehicles are used. For instance, each metro line uses a different model of train. Some bus lines use simple vehicles that can carry around 50 to 70 passengers, whereas rapid transit lines use articulated buses that can carry up to 155 passengers. We assume a capacity of 350 passengers for metros, 220 passengers for tramways, and 80 passengers for buses even though this number is underestimated for rapid transit lines.
The bar charts of Figure 4 show, for each vehicle type and each scenario, the proportion of lines which never overrun their capacity (upper bar section), the proportion of lines which overrun their capacity at least once by more than 1.5 times the capacity (lower bar section), and the proportion of lines which overrun their capacity at least once but never more than by 1.5 times the capacity (middle bar section). Let us underline that these charts do not give any information on the time spent with capacity excesses.
Tramways almost never exceed their capacity. The capacity is only exceeded in scenario 0, and

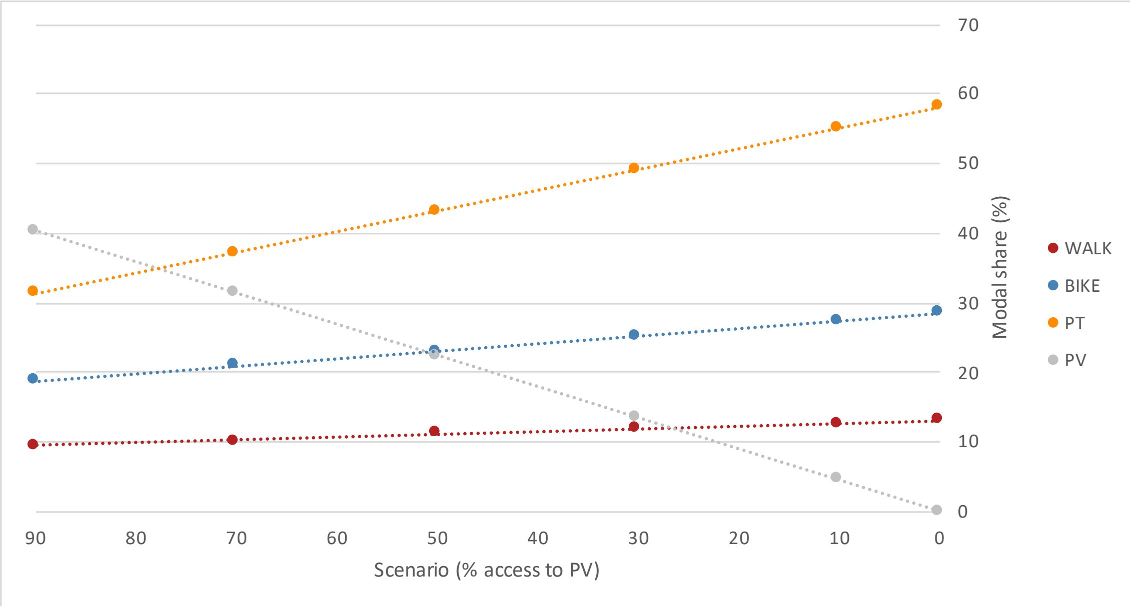


Figure 3: Evolution of modal share from scenario 90 to 0. The dotted lines represent linear tendency curves. All curves have $R^2 > 0.98$.

only for one tram line (Figure 4.a). For metros, only one line exceeds its capacity by more than 50%, for scenarios 70 to 0. A second line exceeds its capacity by less than 50% for scenarios 70 to 0, and a third one for scenarios 10 and 0 (Figure 4.b). Buses present the highest rate of capacity overrun (Figure 4.c). Even in scenario 90, 40% of bus lines exceed their capacity (by less or more than 50%). In scenario 0, The share of buses that exceed their capacity rises up to 65%, which represent more than 40 bus lines. Theses results should be mitigated by the fact that, as we said, buses have the highest variability in terms of capacity. However, they tend to show that optimizing the bus network would be an important step towards car-free urban mobility in Lyon, at least in terms of transport capacities.

Realism of the simulation

Even though we did not simulate a reference scenario modeling the reality in terms of access to transport modes, we find that our results are consistent with the observed modal share in Lyon. According to (Observatoire des Territoires, 2021), 60.1% of households had at least one car in 2021, and according to (UrbaLyon, 2019), 26% of urban trips were done by car in 2015 in Lyon. If we refer to Figure 3, in a 60% car prevalence scenario, we could expect the modal share of personal vehicles to be around 27%. However this consistency has to be mitigated by the fact that the trips considered by (UrbaLyon, 2019) are not necessarily of the same nature than the trips of the simulation. For instance, (UrbaLyon, 2019) counts 45% of walking trips, whereas we would expect only 10% of walkers in a 60% car prevalence scenario (Figure 3). This may be due to the fact that in our case, the origin-destination matrix only takes into account the trips between two different origin-destination zones, hence ignoring intra-zones trips that would typically be made by foot.
The discrete choice model used should also be questioned. In this study, we used a logit decision model on which we do not have full control. Moreover, human decisions are far from being rational. In terms of transport, they are motivated not only by the economic cost and travel time, as it is the case in this simulation, but also by the user's comfort, lifestyle, family responsibilities, opinions, beliefs and biases. For now, we do not have a clear enough view on the realism of our choice model, given that it only takes into account two of many choice criterions. The impacts on the simulation outputs of using a limited choice model are also unclear and we are not able to tell whether or not a more complex model would make a significant difference.

4 Conclusions and perspectives

In this article, we proposed a preliminary study using a simulation method to evaluate some of the impacts of the suppression of private cars in the city of Lyon. With the prospect of suppressing

private cars, the results are encouraging: half of the users see no increase in their travel time between scenario 90 and scenario 0, and most tramway and metro lines would not exceed their capacity even in scenario 0. However, some other results indicate that improvements of the public transport network are necessary for several reasons.
First, the current public transport network would not be sufficient to absorb the mobility demand in a car-free scenario. It would be necessary to either decrease the headway or increase the capacity of the vehicles on more than 60% of bus lines, as well as on some metro and tramway lines. These modifications are enhancements of the existing network and cannot be avoided if we want to create a car-free Lyon.
Furthermore some modifications would be required to maintain the quality of transport services despite car suppression. In practical terms, this means that the increase of travel time should be mitigated for public transport to be considered as a viable alternative to private car. Four hypotheses are formulated to explain the travel time increase when switching from car to public transport, which require further investigation. Depending on which of these hypotheses are true, several solutions can be considered, among which: decreasing the headway between vehicles, extending existing lines by adding stops, adding new lines that better fit the requirements of the origin-destination pairs.
Similar simulations and analyses are conducted for the cities of Athens and Amsterdam. Further work will also include the study of artificial cities with various topological, geographical, and mobility related characteristics.

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The authors confirm their contribution to the paper as follows:

- Study and conception design: Christine Buisson, Fayçal Touzout, Mathilde Nemer;
- Analysis and interpretation of results: Mathilde Nemer, Fayçal Touzout, Christine Buisson;
- Data processing and figure creation: Mathilde Nemer.

All authors reviewed the results and approved the final version of the article.

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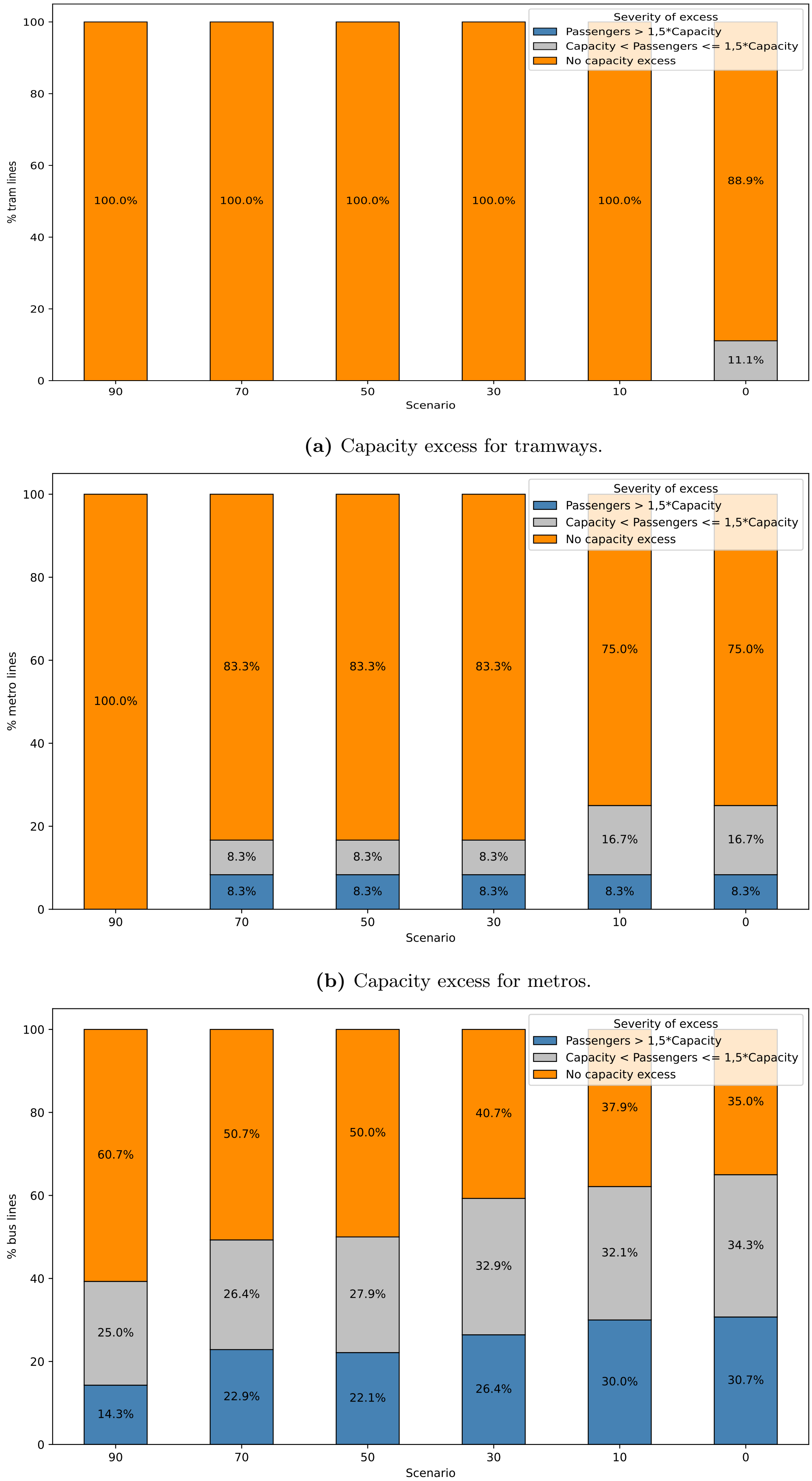

(a) Capacity excess for tramways.

(b) Capacity excess for metros.

(c) Capacity excess for buses.

Figure 4: Share of public transport lines that overrun their capacity.