Evaluating the impact of Free Public Transport using agent-based modeling: the case-study of Luxembourg

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Short summary

Luxembourg's high car ownership per household, combined with a strong population growth and high share of cross-border commuters, led to systematic traffic congestion issues all over the country. To address this problem, the government made public transport (PT) free in 2020 by eliminating second-class fares, a policy that attracted great interest but also led to controversial opinions on its real impact on car use. Notably, since free PT requires no ticketing, there is a problematic lack of passenger data that would allow assessing the policy impacts. Therefore, in this study a MATSim scenario was developed and used to evaluate the impact of this policy under realistic settings. The population was generated using data from a national travel survey collected in 2017 and the free PT scenario was compared against a benchmarking scenario where public transport was still not free, allowing to collect and analyse different KPIs. The simulation showed that the policy brought significant benefits in terms of Passenger Kilometer (PKT) and Hours (PHT) Travelled for PT, and a decrease in car usage in favor of PT especially for cross-border commuters for the parts of their journey that take place inside of Luxembourg. Nonetheless, this study found that the overall impact of Free PT was not significant enough to strongly impact the congestion levels, with the high car ownership rates being one possible reason for this resistance.
Keywords: Agent-based modeling; Free public transport; MATSim.

1 Introduction

The development of new on-demand services, the increasing popularity of car and bike sharing, and the growing trend towards multi-modal travel pose a series of challenges for research groups around the world. These trends, combined with new transport policies, have the potential to significantly impact travel behavior, making the forecast of the impact of such changes essential for policymakers to avoid investing substantial amounts of resources in ineffective measures.
This is particularly relevant for Luxembourg, where in March 2020 all second-class fares were canceled, becoming the first country in the world to provide nationwide free public transportation (PT). The goal of this policy was to reduce the high percentage of trips made by car, which was around 79% in 2017, with 33% being performed by cross-border workers who reside in France, Germany, and Belgium. This convergence of travelers onto specific segments of the network leads to severe congestion and significant increases in travel time during peak hours.
Understanding the impact of transport policies such as free-PT is a non-trivial task, since it requires estimating the mode choice elasticity for all trips performed by an individual in a context where many other factors may have caused an equal or even stronger effect (e.g. the COVID19 pandemic). Moreover, such policies are expected to have an impact on the whole trip chain, hence requiring more sophisticated approaches than the traditional trip-based approach. Conversely, agent-based demand modeling designed to further test new transport models allows a better forecast of traffic demand on the network, and a more accurate policy evaluation. The main goal of this study is to investigate the impact of the policy put into action in 2020, using the MATSim agent-based simulation (Horni et al. (2016)) scenario developed for Luxembourg.
The developed scenario simulates the main modes of transportation including cars, PT, biking, and walking. It provides detailed schedules for public transport services such as buses, trams, and trains. The transportation network generation was set up using two open data sources: network information from OpenStreetMap (OSM) and public transport schedules generated from the

General Transit Feed Specification (GTFS). The population generation and trip chains, as well as the origin-destination matrices, were obtained from the LuxMobil travel survey conducted in 2017. After the population was generated and the MATSim scenario was calibrated using the data from the travel survey, as well as traffic counts, the impact of the Free Public Transport policy in Luxembourg was analyzed. The aim of this study is therefore to evaluate the Free Fare Public Transport (FFPT) policy in Luxembourg. The study will tackle the evaluation of this policy from various perspectives, such as travel time reduction, travel distance decrease, modal split shift, and cost-benefit analysis.

Literature Review

Free public transport has been a topic of interest for many cities and countries worldwide, seen as a means to reduce traffic congestion, improve air quality, and provide affordable transportation to citizens. Many studies have been conducted on this topic. Kębłowski (2017) presents an analysis of the various models of Free Public Transport implemented globally. It categorizes these models into two categories, the FFPT and Partial FFPT. FFPT is defined as PT systems in which the free service is widely available and accessible to the majority of users throughout the majority of the time. On the other hand, Partial FFPT is a ticket-free system that is limited in some way, such as being restricted by space, time, or in terms of user groups. Guelton & Poinsot (2020) focuses on fare-free public transportation in France and its increasing availability, as well as working financial models for this policy in the context of limited public funds. According to Duhamel (2004), the FFPT can be considered as a viable option only for cities with low ticketing revenue and passenger volumes prior to implementation.
Given the complexity of impacts that this policy can have in different contexts, the academic community is divided in their opinion. Studies by Studenmund & Connor (1982) and Brown et al. (2003) support the notion that ticket-free systems can attract car users to public transportation, even after fares are reinstated, settling the obtained shift in the modal split towards Public Transport in favor of cars. Bull et al. (2021) proves with their study the effectiveness of this policy in increasing the modal share of PT in Santiago, Chile. Conversely, Volinski (2012) highlights FFPT's limited achievements in generating a modal shift from private vehicles to PT in terms of cost and resources to be sustained by the companies. The study of Cats et al. (2017) highlights the limited impact of FFPT on sustainable development and suggests that it may cause financial instability in public transportation systems, resulting in irrational travel patterns and unproductive mobility. In the case of Luxembourg, this could result in PT becoming a competitor with walking as a mode of transportation for short trips of less than 500 meters.
Nonetheless, several cities have implemented free public transport policies, with varying degrees of success. Many European municipalities justify FFPT as a strategy working towards reducing car usage (e.g. Avesta, Sweden) and car-related pollution and noise (e.g. Livigno, Italy) and thereby increasing the liveability of the city itself. A study from the city of Tallinn provides an empirical evaluation of the impact of FFPT on service performance, passenger demand, and accessibility, showing that this policy led to an increase of 1.2% in passenger demand for PT, while highlighting that the relatively small impact could be attributed to the previous price level and public transport share, as well as the short-term impact, Cats et al. (2017). The important difference with the case of Luxembourg is that a ticketing system is still applied, where the residents don't pay for the PT whereas tourists and visitors have to pay standard fares. In a similar context, the french city of Dunkerque implemented a Partial FFPT policy in 2018, Briche & Huré (2018): they showed that this policy is sustainable and synergizes with urban development while also being mindful of the needs of low-income populations. In this study, free transportation is proven technically and financially feasible for an urban area of 200,000 residents, debunking the hypothesis that it is only applicable to medium-sized cities.

2 Methodology

Survey Data

In this work, the data used to generate the agents' population is extracted from the LuxMobil travel survey, which was conducted in 2017, whose aim was to draw a picture of mobility throughout the country of Luxembourg, and contained information of both residents as well as cross-border workers. In the survey, a total of 33,207 individuals were asked to provide their socio-demographic

information and a travel diary for a typical day, with detailed trip chain information such as main modes of transport for each trip, travel time, origin, and destination. The respondents were 66% from Luxembourg, 15% from France, 10% from Germany, and 9% from Belgium. This study included 218 zones, with 71 of those being from Belgium, France, and Germany.

Data cleaning

After excluding all individuals who declared not to perform any activities, the population sample size was reduced to 22,199 respondents (67% of all interviewees) without altering substantially the distribution of the population in terms of resident/crossborders. Considering the total population moving in the area of the sample (around 197.000 cross borders, together with 645000 in Luxembourg Residents)[1], the MATSim synthetic population represents approximately 2% of the population, with agents carrying out activities of various types such as home, work, school, shopping, leisure, and others.
From the travel survey, we extracted 85506 trips, each with an associated main mode of transport, and estimated the modal split for a weekday, which is divided as follows: 79% Car, 16% PT, 1% bicycle legs, and 4% walk legs. Demand generation and activity location assignment were based on 24-hour activity OD (Origin-Destination) matrices generated from the travel survey data. The source data for the MATSim Luxembourg road and PT network was obtained from OSM and GTFS files using the pt2matsim tool Poletti (2016). To simplify the analysis, the 216 areas were merged into 146 zones, with 3 of these zones representing the three neighboring countries. This was due to the limited population density data available for some of the foreign areas in the travel survey and the focus on the Luxembourgish road and PT network. To try to maintain as much accuracy as possible on the data regarding cross-border commuters, a "bee-line" moving approach was utilized, which involved relocating their house location to the nearest centroid and adjusting their first and last activity times based on their declared mode of transport and average speed. This was calculated using the beeline distance between the declared position of the house and the closest centroid. Moreover, regarding the cross-border commuters, since there were no interviews performed on people under the age of 18 in the survey, we assumed that they would all hold valid driving licenses. Car availability was then determined based on the area and household aggregation. While this approach could alter travel behavior if coupled with a strong mode replanning strategy, it ultimately proved to be an effective solution as the data remained consistent.

Calibration of the MATSim simulation

In order to calibrate the scenario prior to the free PT policy (Pay-PT), we run different MATSim simulations with 10% of the overall population (around 64000 agents) to reach a steady state. This was achieved by performing multiple simulations, each with 250 iterations, starting from the parameters used for the Berlin scenario, Ziemke et al. (2019). The scoring parameters were adjusted after each simulation until convergence was achieved with the traffic count data, as well as with the modal split, average travel time, and average distance per mode per leg from the Luxmobil travel survey. The volume on the main congested roads that are leading to the foreign centroids was then compared to the real traffic counts, showing adherence with the initial data. In order to reproduce the FFTP system, the monetary constant was set to 0. Nonetheless, the calibration process for the FFTP Scenario turned out to be a challenging task. The biggest obstacle encountered was the absence of a ticketing system for every PT, making it difficult especially for busses to determine the actual number of passengers, paired with the presence of multiple PT providers. However, for trains and trams, data is available regarding the passenger-km performed[2], which was then matched with the corresponding data from the simulation.

[1] `https://luxembourg.public.lu/en/society-and-culture/population/demographics.html`

[2] `https://gouvernement.lu/fr/publications/rapport-activite/minist-mobilite-travaux-publics/departement-mobilite-transports/2021-rapport-activite-dmt.html`

3 Results and discussion

Table 1 and Table 2 present the results of the effect of the Free PT policy, segmented between Luxembourg Residents and Crossborders, and the overall comparison between the Pay-PT scenario and the Free-PT scenario. The asterisk in the Tables (*) indicates that the sample size for these modes of transport was too small, leading to unrealistic results in the simulation.

	Comparison - Paid PT vs Free PT				
	AVG Leg TT	**AVG Leg Distance**	**PKT**	**PHT**	**Modal Split**
	Resident				
Car	-5%	-4%	-12%	-13%	*
Walk	3%	-2%	*	*	*
PT	-11%	-9%	8%	5%	*
Bike	18%	18%	*	*	*
	Crossborders				
Car	-1%	-2%	2%	3%	*
Walk	17%	6%	*	*	*
PT	-13%	-12%	61%	60%	*
Bike	7%	7%	*	*	*
	Overall				
Car	-2%	-1%	-8%	-8%	-10%
Walk	9%	2%	*	*	0%
PT	-12%	-9%	19%	16%	10%
Bike	12%	12%	*	*	0%

Table 1: Analysed KPIs - Pay vs Free PT

Table 1 compares the difference between the Pay-PT and Free-PT scenarios in terms of average Leg travel time and distance, person-kilometers traveled (PKT), and person-hours traveled (PHT). The policy appears to impact all transportation modes: for Residents, the use of public transportation increased, as seen as an increase in the PKT and PHT, with a corresponding decrease in leg travel time and distance. The policy had a greater impact on the Crossborders, resulting in a 60% rise in PKT and PHT, demonstrating that public transportation became a more appealing option for their daily journeys. It has to be noted that these numbers are likely overestimated, as the FFPT policy is available only for PT trips performed *within* Luxembourg, not for trips originating from the Greater Region. Nevertheless, these results show that extending the FFPT policy to cover cross-border trips from external countries to Luxembourg could have a substantial impact, given that a large proportion of commuters travel long distances. Overall, the Free PT affected the agent's travel behavior, as seen in an increase in PKT and PHT for PKT, together with a Modal Split change that presents a 10% of car users switching to public transportation.
Table 2 presents information on the changes in the trips' mode of transportation. For trips performed by Residents, PT was favored over cars for all the considered segments, which led to a decrease in car usage. On the other hand, the free-PT policy had a noteworthy impact on cross-border in terms of a reduction of trips performed by cars in all the considered segments. Nonetheless, considering cross-border commuters were the target group for the policy as they travel on average more than 25 km to their main activity (an average of 35.3 km as per our travel survey), the impact is very limited. The reluctance of these commuters to switch modes of transportation is shown by a slight increase in the PT choice for all the segments, and especially the limited impact is highlighted by the slight PT trips increase in the > 25 km trip segment, which accounts for the largest portion of trips. This is also linked to the high PKT and PHT for PT for Crossborders presented in Table 1, suggesting that cross-border travelers could find PT to be convenient, and willing to travel further to reach their destination. This could be due to several reasons, including the lack of effective connections to foreign countries and the high car dependency of the country with 676 passenger cars for every 1000 inhabitants and being the country with one of the highest mobility expenditures in Europe.

	% of trip difference for specific distance segments - Paid PT vs Free PT			
	Resident			
	trip <5 km		**5 km <trip <10km**	
	trips (Paid PT)	*Paid PT vs Free PT*	*trips (Paid PT)*	*Paid PT vs Free PT*
Car	30449	-4%	16361	-2%
Walk	10835	1%	90	0%
PT	520	1%	335	1%
Bike	448	2%	56	1%
	10 km <trip <25 km		**trip >25 km**	
Car	21670	-2%	27761	-3%
Walk	60	0%	15	0%
PT	904	1%	3019	1%
Bike	68	1%	120	2%
	Crossborders			
	trip <5 km		**5 km <trip <10km**	
	trips (Paid PT)	*Paid PT vs Free PT*	*trips (Paid PT)*	*Paid PT vs Free PT*
Car	678	-4%	988	-10%
Walk	934	2%	68	3%
PT	30	2%	113	7%
Bike	19	0%	45	1%
	10 km <trip <25 km		**trip >25 km**	
Car	3787	-5%	22694	-5%
Walk	79	0%	41	0%
PT	60	1%	734	2%
Bike	64	4%	248	3%
	Overall			
	trip <5 km		**5 km <trip <10km**	
	trips (Paid PT)	*Paid PT vs Free PT*	*trips (Paid PT)*	*Paid PT vs Free PT*
Car	31127	-4%	17348	-3%
Walk	11768	1%	158	0%
PT	550	1%	448	2%
Bike	467	2%	102	1%
	10 km <trip <25 km		**trip >25 km**	
Car	25457	-3%	50455	-4%
Walk	139	0%	56	0%
PT	964	1%	3753	2%
Bike	132	1%	369	2%

Table 2: % of trip difference within specific trip segments - Paid PT vs Free PT

4 Conclusions

This paper analyses the impact of Free Public Transport in the context of Luxembourg, based on a MATSim scenario calibrated through survey data. The results demonstrate the effects of this policy on the country, where benefits can be seen in the increase of the overall choice for PT as a main mode of transport, seen as an increase in the PKT and PHT, together with a shift in the modal split. However, the policy slightly impacted cross-border travelers, with a significant increase in their travel time if using public transport, and indeed resistance has been observed in the expected modal shift.

Future research includes the investigation of the impact of the 1 PT-stop trips and how these affect the whole system, given that before 2020 Luxembourg already included an integrated ticketing system so without a real time-gain on the ticket validation to be done in-vehicle, especially for busses; a deeper study on the cross-border behavior and which policies could be put in place to reduce the still very high car mode share in the country; the implementation of the different on-demand services which are already present in the country (such as bike and car-sharing, taxi, car-pooling etc,..) and a comparison with the obtained data for the PT scenario with the real data

that will be made available in 2023 by the national statistic agency STATEC.

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