Modelling for Sustainability
Model Assignment

Predictive Model

"*How will a zero-fare public transport policy affect motorization rates and other modes of transport in the future?*"

Group 5
Leo Broussard
Elisa van Overbeke
Ward Ovezall
Sabine Dominioni

Introduction

According to the European Environment Agency, air pollutant concentrations in Europe remain too high with air quality problems persisting, despite a decrease in emissions over the past decades (EEA:2020). Such air pollution does not only pose serious health risks for citizens, 90% of whom are exposed to harmful pollutant levels but pressing environmental consequences such as acidification, eutrophication, and crop damage (idem). Hence, many European countries have set out policies and plans to reduce such anthropogenic emissions. Reducing carbon emissions worldwide appears as a key challenge, especially in the transport sector. The air pollution emitted from motorized fossil-fueled vehicles is widely accepted as one of the central causes of these issues, especially in metropolitan cities. In 2016, transport generated ca. 8 gigatonnes of CO_2 globally, with road transport accounting for 74% of these emissions, followed by air- (12%) and waterborne transport (11%); cars account for almost 44% of transport GHG emissions in the EU. To be on a sustainable path, the transport system needs to substantially reduce the level of air pollution and greenhouse gas (GHG) emissions it emits annually. (Vilchez et al., 2019).

Therefore, many nations have turned to public transport as a potential intermediate solution to high motorization rates across Europe, and several countries have already implemented networks of electric vehicles running on renewable energy (Sheung: 2020). However, the only country that has managed to make public transport completely free thus far is Luxembourg. According to the Ministry of Mobility and Public Works, the Luxembourg government is hoping for environmental benefits as well as alleviating heavy congestion (Tomes et al: 2022). Luxemburg has had the highest motorization levels in Europe for years, and this free public transport scheme has inspired hopes that these numbers will decrease in the coming years. In 2022, Malta also followed in Luxembourg's footsteps by implementing a zero-fare policy, as well as Spain and the Italian region of Friuli-Venezia Giulia, launching free train travel on specific routes for a limited period. However, these zero-fare policies only offer insights at the local scale, for either microstates or specific regions/routes, and not at a global scale. Luxemburg has had the highest motorization levels in Europe for years, and this free public transport scheme has inspired hopes that these numbers will decrease in the future.

Moreover, with the increased awareness of the degradation of the environment, consumer's environmental concern has increased (Ramayah et al. 2012; Chen and Tung 2014) which we predict will allow a decrease in motorization rates for fossil-fueled cars or at the very least, more electrical vehicles. This project will aim to provide a predictive agent-based model of the change in willingness to use public transport and the future motorization rates of Luxembourg following the free transport policy. It is hypothesised that the use of public transport will remain stagnant at first, but after the creation of habits of use within society, its use will exponentially increase, while motorization rates will decrease; this model will allow us to accept or reject this hypothesis and offer a framework for potential policy change in public transport fares in other nations.

The results of this model will be relevant in understanding the role of public transport in climate change and CO2 levels, and whether making it free is a possible solution to said emissions with environmental and health consequences due to air pollution, as well as boosting investment worldwide in the public transport sector to combat climate change. The research question is the following: *How will a zero-fare public transport policy affect motorization rates and other modes of transport in the future?*

Theoretical framework:

The application of various theories and concepts are necessary in order to understand the different dynamics between the variables and parameters used in our netlogo computer model. Our computer model is used in conjunction to the theoretical MOA model of motivation, opportunity and ability for the use of public transport (Thogersen: 2009). The MOA model is based on both Azjen's (1991) theories of planned behaviour and reasoned action, which explore motivations, intentions, and subjective norms as the roots of behavioural outcomes. The 3 different components from the MOA model will be operationalised in this theoretical framework to make more sense of our computer model.

Motivation/ Veblen's Theory of the Leisure class (1899)

The motivation aspect of the MOA model refers to values and beliefs. In a consumerist society, many people are motivated by social status, and hence take this into account when making a purchase. The "Veblen Effect" describes this phenomenon, explaining that sometimes people are willing to pay a higher price for a product that is equally or even less functionally equivalent than cheaper alternatives, as they see this aspect as a form of utility (Bagwell and Bernheim: 1996). Therefore, some people's beliefs and values may lead them to prioritise greater status above functionality and price utility. Individuals who seek such social status often do so to reproduce patterns of consumption from people above them in a social hierarchy (Erikson: 1993, Mason: 1998). In the netlogo model: "Social Inequity in Transportation System", this social status 'utility' is represented in the 'mode profile' graph, and affects people's decisions whether to use cars or public transport. Therefore, the mode of transport which has the highest cost is considered more 'luxurious', thus affecting people's willingness to pay more for such transport in order to obtain greater social status. The higher the cost disparity between the two modes of transport in this model, the more luxurious the more expensive model is perceived by consumers.

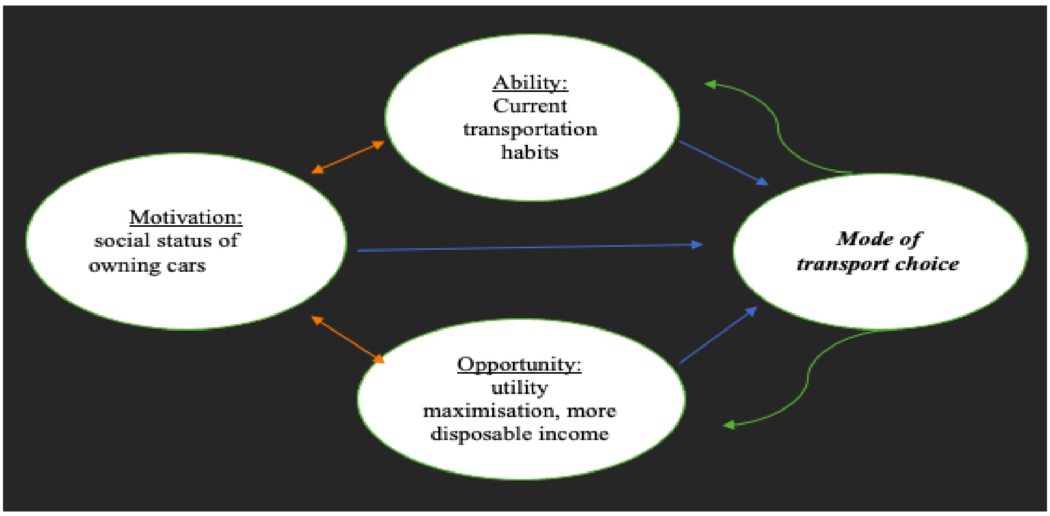
Opportunity – Utility maximisation

Although both theoretical and computer models in this paper acknowledge social factors that explain behaviour, it cannot be ignored that humans act as rational actors. When it comes to pricing, there is an overwhelming academic consensus that individuals seek to maximise their profits and satisfaction (Kooreman: 1993). A high utility means that an economic decision has proved to be efficient both in terms of price and satisfaction: in other words, people get the most utility possible out of their money for the lowest price possible from certain transactions (Hess et al: 2018). Therefore, it is assumed that the price of a given mode of transport will have a significant effect on the rate in which it is being used. Utility maximisation is represented in the netlogo model by adjusting car prices and public transport fares.

Ability – Habits

On top of Veblen's theory and utility maximisation, habits are an important factor influencing people's choice of transport. A habit is formed when behaviour is being consistently repeated over time, leading to favourable outcomes (Ouellette and Wood: 1998). These behaviour patterns are true for most people's everyday transport choices. In order to break a habit, something must happen to make them seem unfavourable, with sufficient incentive to make different habitual choices. For example, when presented with a free month of travel card, people in Copenhagen did not only switch their habits during this time due to the price change, but also for over 5 months after the free public transport had ended (Thogersen: 2009). This proves that for some people, significant pricing changes are a sufficient incentive to break their daily habits.

Motivation (Veblen's Theory), Opportunity (Utility maximisation), and Ability (habits) are all used to define and shape a person's perceived utility of using public transport, which is measured in the netlogo model as 'THRESHOLD'. This parameter is measured from 0-1, 1 being the highest level of perceived utility for public transport use. The above theories and the traditional MOA model have been utilised to create our own model diagram relating to zero fare public transport on motorization rates:



Methods

In this paper, we will explore a predictive model to answer our research question, which will be based on previous research and behavioural models on the effect of financial incentives on the use of public transport and the transition to more sustainable modes of transport. The conceptual model is adapted from a Motivation-Opportunities-Ability model (MOA) to our own research, for which opportunity (free public transports in this research) and ability (habits in this research) are parameters for Behavior (change in the use of transports, here) as the predicted variable. We will be using the application approach with an agent-based model of transport-mode-choice behaviour, “Social Inequity in Transportation Model” using the modelling software *Net logo*. Since it is evident that a reduction in the price of public transportation results in additional income for the user (agents), this model will delve into the consequences of higher disposable income on motorization rates. It is an agent-based model of artificial agents who live in an artificial world of patches. Each agent occupies a single patch and interacts with its neighbours. They will then update their state, either purchasing a car or using public transportation, according to a probability function. The higher the difference between an agent’s wealth to her neighbours’, the higher the probability of the agent purchasing a car. The model has three parameters, fare (price of public transport; ranging from 0 to .99), buy price (of a car; ranging from 0 to 5), and threshold (perceived utility of using public transport mode, 0 to 1). The model presents two graphs: mode shift which shows the number of agents buying a car or using public transports, while the mode profile shows the prestige value of buying a car or using public transport. Assessing the possible interaction in the price of public transport and motorization rates, as well as compounding previous research, will allow us to form an answer to the possible interaction between financial incentives and alternative modes of transport, however, since the data isn’t Luxembourg specific, the results will need to be taken with reservations, and rather be seen as a way to examine the effectiveness of the zero-fare policy.

Results

In order to analyse the different outcomes depending on the degree of each parameter, five combinations were made from the Netlogo outputs (see Appendix).

Combination 1: Fare = 0; Buying Price = 5; Threshold = 1

Combination 2 : Fare = 0; Buying Price = 5; Threshold = 0

Combination 3: Fare = 0; Buying Price = 2.5; Threshold = 1

Combination 4: Fare = 0; Buying Price = 2.5; Threshold = 0

Combination 5: Fare = 0.5; Buying Price = 2.5; Threshold = 0.5

The four first combinations will allow for the analysis of the effect of the buying price of a car and perceived utility of using public transports, at various levels, under a zero-fare policy; while the fifth combination will be used as a sort of control group in which the zero-fare policy isn't enforced.

Two output tables were made, *Transport use* and *Prestige value*.
The *Transport use (*mode shift*)* outputs were selected in three different "phases", the first value (*start*), the value before stabilisation (*maturity*), and the average value when the values stabilise (*stabilisation*). It is important to note that the car variable always starts at 0.
The *Prestige value* (mode profile) outputs were selected in two different "phases", the highest value before stabilisation (*peak*), and the average value when the values stabilise (*stabilisation*). It is important to note that in the raw output, the car variable always starts at 0, while the transport variable starts at 0.5 when the fare is set at 0, and 0.75 when the fare is at 0.5. Furthermore, the values are arbitrary, but it allows to have an idea of the magnitude of the effect depending on the settings.

Table 1. Transport Use

Settings	Type of transport	Start	Maturity	Stabilisation
Combination 1	Public	3705	3147 (21)	3383
	Car	0	574 (21)	337
Combination 2	Public	3703	2368 (19)	2540
	Car	0	1350 (19)	1150
Combination 3	Public	3708	2616 (20)	2800
	Car	0	1103 (20)	900
Combination 4	Public	3696	1956 (22)	1900
	Car	0	1755 (22)	1900
Combination 5	Public	1826	3009 (13)	2700
	Car	0	729 (47)	550

Note. (.) represents the time (ticks in model) of the value.

Table 2. Prestige Value

Settings	Type of transport	Peak	Stabilisation
Combination 1	Public	3.18 (20)	2.95
	Car	13.35 (10)	7.5
Combination 2	Public	2.61 (13)	2.2
	Car	5.24 (13)	4.9
Combination 3	Public	N/A	2
	Car	67.22 (6)	drop 4.39 (25) then 5.1
Combination 4	Public	1.49 (9)	1.37
	Car	2.87 (9)	2.9
Combination 5	Public	N/A	1.6
	Car	6.69 (9)	5.4

Note. (.) represents the time (ticks in model) of the value. N/A means non applicable, in that case, it represents the lack of a clear peak; the curve rapidly stabilized.

In order to read the effects of a change in car or public transportation use from the two tables, we need to compare the fifth combination where the fare parameter is set at 0.5, to the first four combinations. As the fifth combination is set out as the starting point where the zero-fare policy is not installed, the differences in car and public transportation use compared to when the zero-fare policy is installed can show us the effects of the policy. The first four combinations all have the fare parameter set at a 0 value, but differ in the values of the remaining parameters.

The results in Table 1. show that in the first combination, where the zero-fare policy is installed and the price someone should pay for a car as well as the perceived utility is high, the use of public transport rises and the use of cars declines compared to combination 5.

Combination 2 shows that even with a zero-fare policy at play and a high car price, when there is no perceived utility in using public transportation, car use will only continue to rise and public transportation use declines. Combination 3 shows a logical result compared to combination 1, where car use rises and public transportation use declines when the buying price of a car declines. Combination 4 shows an interesting result in the stabilisation values, where both car use and use of public transportation are around the same value. The ‘threshold’ parameter seems to have the strongest effect on car- and public transportation use.

Table 2. shows quite coherent results when it comes to the difference in stabilisation value between the use of public transportation and buying a car. With every combination used, the prestige value of a car seemed to be higher than that of public transportation. For instance, combination 1 records 13.35 (peak) and 7.5 (stabilisation) for the car variable while 3.18 (peak) and 2.95 (stabilisation) for public transport. What we can observe is that whenever the buying price of a car or the perceived utility of

public transportation goes down, both prestige values decline. Although both prestige values decline in about direct proportion to each other, we can still observe a rise in the use of cars in Table 1.
Looking at both tables, we can observe that when the price parameters are set to favour a public transportation oriented system, the prestige of cars turned out to be the highest. This can be theorised by stating that because the use of a car is seen as more costly compared to public transportation, it gets granted a luxury status.

Discussion

Another manner by which our research was depicted was through the tables 1-10 found under the index. In combination one, it is observed that the number of 'agents' (or individuals using cars as their main transport) are quite high compared to public transport. In addition to this, the difference in buying prices the profiles have are quite strong. This signifies that the car is heavily privileged in terms of upholding a potentially higher social class than those with public profiles. However, when you compare this to table three (which belongs in combination two), it reveals that if you increase the number of cars on the road (hence decrease the difference in number of the people who take a motor vehicle versus public transport), the contrast between public profiles shrinks. This suggests that the more people have cars, the less it is seen as an absolute luxury. In fact, combination four shows a result which strongly supports the previous statement given: when the car value is set at 1858 and public transport at 1862, there is virtually very little distance in the profile graph, with 2.931 for cars and 1.327 for public transport. Deductively, it also proposes that the lower the buying price, the more the transport service will be used. It also infers that the long-term use of public transport will potentially be a leading cause to congestion seen on highways and other roads. As hinted upon in the methods section, what public transport users choose to do with their additional income generated from taking a cheaper carrier service depends on two main factors: social class and habit abilities.

Implications & Limitations

'All models are wrong, but some are useful'. For our research about the effect of a free public transport policy on the motorization rate and modes of transport used in the future, some notes on the limitations of our model have to be acknowledged.
The main limitation that can be acknowledged within our research, is that a consumer's change in mode of transportation is a complex process involving more than just factors like the costs of transportation and perceived prestige resulting from a particular mode of transport. Factors like comfortability of using a mode of transport, efficiency of time use within a transportation system, availability of modes of transport within the area could all play a role in altering consumer decision making. Considering this is a sustainability concept as well, consumer's perceptions regarding sustainability and pollution could also be at play within this process. All these factors considering the actors' norms, values, and beliefs are very hard to measure and showed high levels of complexity to

incorporate in our model. If incorporated, it would be impossible to read our results and single out the effect of a policy change in fares.

As previously explained with the MOA model, habits are also of influence on actual behaviour. Habits are one among an array of examples where human behaviour is not always fully rational. Predicting these irrational conditions is hardly possible and causes some inherent flaws in the execution of or research and model.

Lastly, within our research, we focus on the national scale, since the change in policy is also implemented on the national level. But this introduces some challenges considering the fact that public transport availability differs among and within regions. Different modes of public transportation systems like buses, trains, and trams aren't developed in particular regions, due to insignificant demand and a limited possibility for developing infrastructure due to obstructions. So the effects of a change in public transport policy might not have the same effect on the actors behaviour on the entire national level. This is something we could not control for in our model.

Further research on the subject could provide insightful information about the effects of certain policies on the used modes of transportation within certain regions. With a focus on the effects of a zero-fare policy, a more sustainable transportation system could be realised. Since traffic congestion and the excessive use of cars are one of the main drivers of regional air pollution CO_2 emissions, finding ways to reduce this problem are of utmost academic relevance. This research project sets a framework and theoretical basis for further exploration of policy changes in transportation creating sustainability. Adding data on car use and public transportation use from a region could provide insights on what policies could bring about the best result, expanding on the framework we built.

Conclusion

To conclude, this paper has scrutinised and evaluated the efficiency of a motivation-opportunity-ability (MOA) model. By generating the numerous tables and graphs found in the index below, many deductions were made from the abundant results concerning individuals which used cars and which used public transport in the netlogo model. While it is nearly impossible to predict a consumer's choice in transport service, this prototype remains extremely relevant in offering an introspection into the factors which determine this decision. It has also permitted for an analysis in the socio-economic impacts of transportation choice, leading to a possible answer to the original hypothesis proposed: "the use of public transport will remain stagnant at first, but after the creation of habits of use within society, its use will exponentially increase, while motorization rates will decrease". After having conducted this experiment, the hypothesis suggested is validated as public transportation use did strongly increase while motor vehicles experienced a strong decline with zero-fare public transport. As briefly mentioned in the implications, this research gives real insight into how future cities and urban areas may manage their public transport. While the scale of the model posed certain limitations to offer definitive answers, it partially paved the way for future decision-making within the public sector as well as giving awareness to consumer choice. Most importantly, the model results predict that zero-fare public transport policies or other transport related financial incentives have the ability to reduce C02 levels emitted by cars by significantly decreasing motorization rates.

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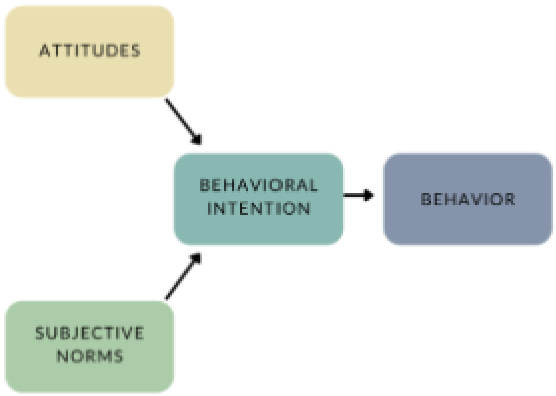
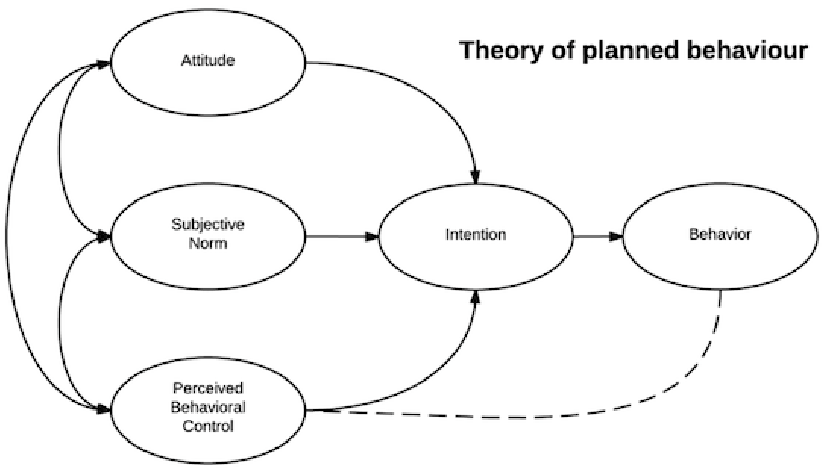
Appendix

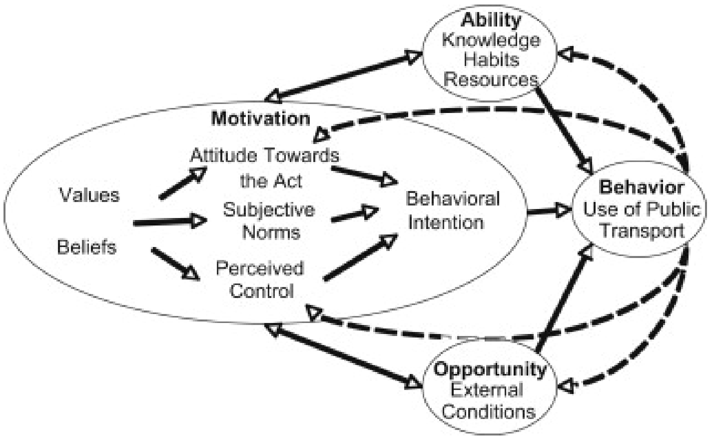
Model of theory of reasoned action (Ajzen: 1967):



Model of theory of planned behaviour (Ajzen's 1991)

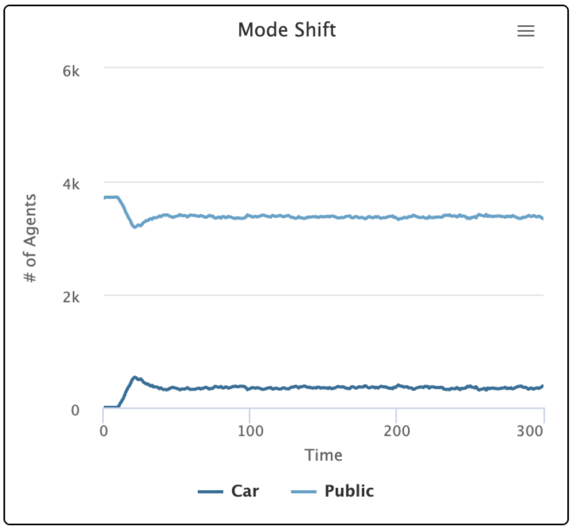


MOA mode (Thogersen: 2009)l:



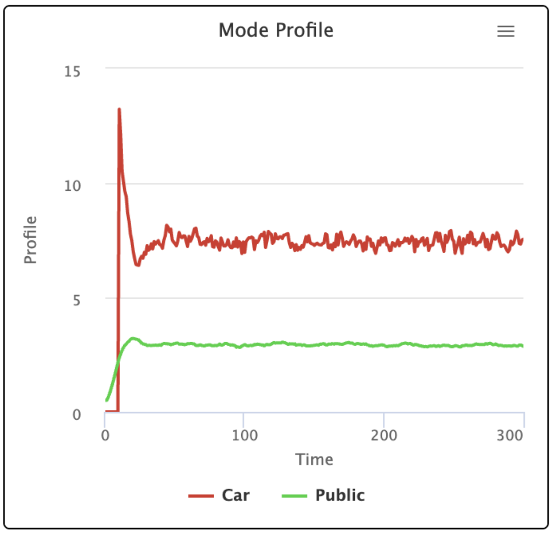
Combination 1.

Table 1



# of cars	# of public
382	3337

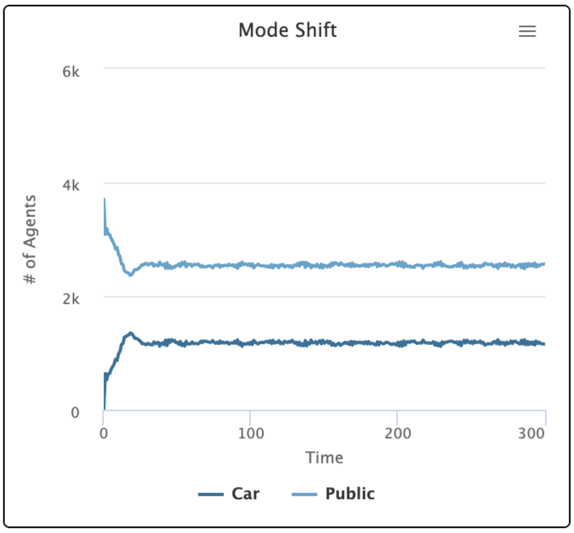
Table 2



Car Profile	Public Profile
7.544	2.862

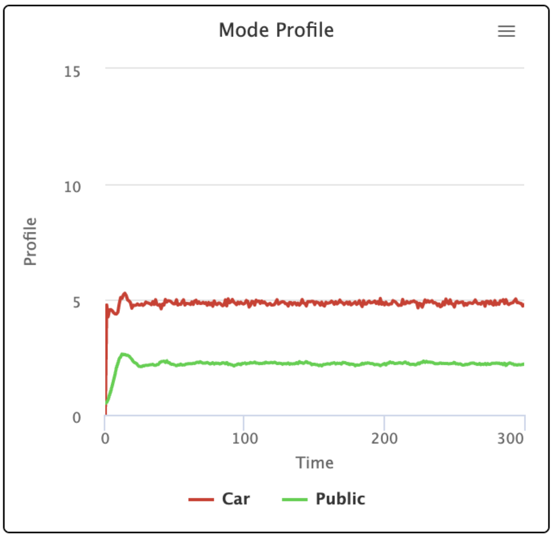
Combination 2.

Table 3



# of cars	# of public
1147	2569

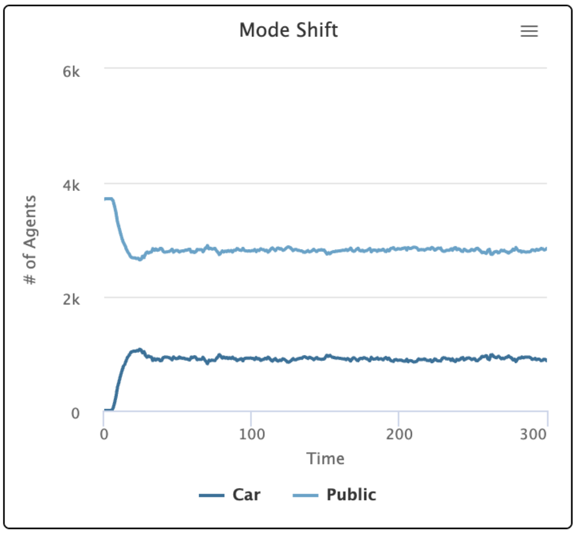
Table 4



Car Profile	Public Profile
4.775	2.199

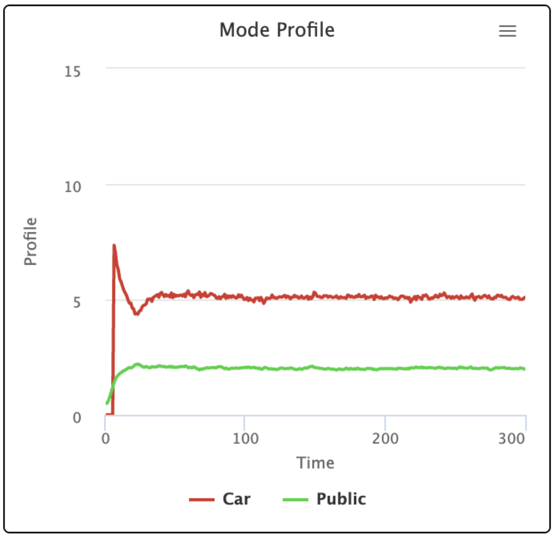
Combination 3.

Table 5



# of cars	# of public
873	2847

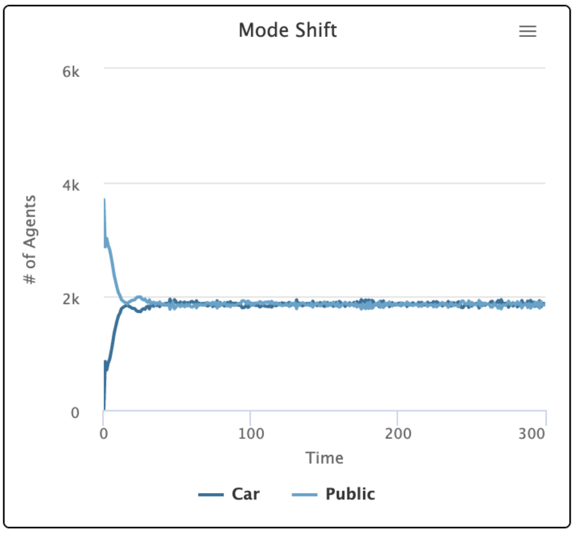
Table 6



Car Profile	Public Profile
5.096	1.982

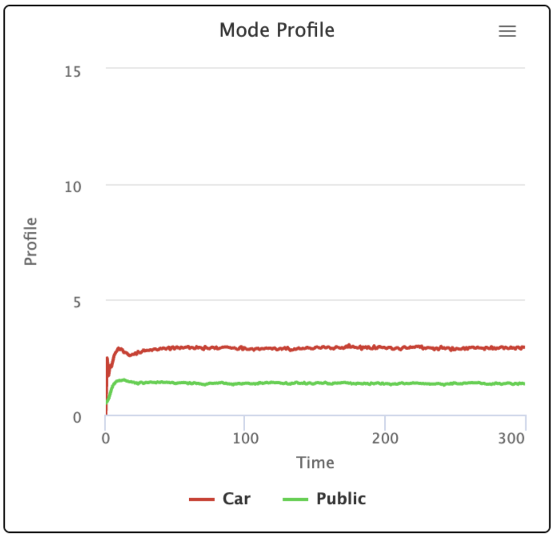
Combination 4.

Table 7



# of cars	# of public
1858	1862

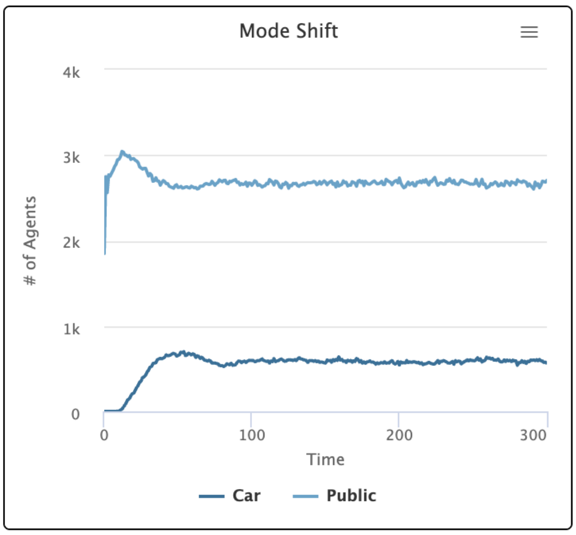
Table 8



Car Profile	Public Profile
2.931	1.327

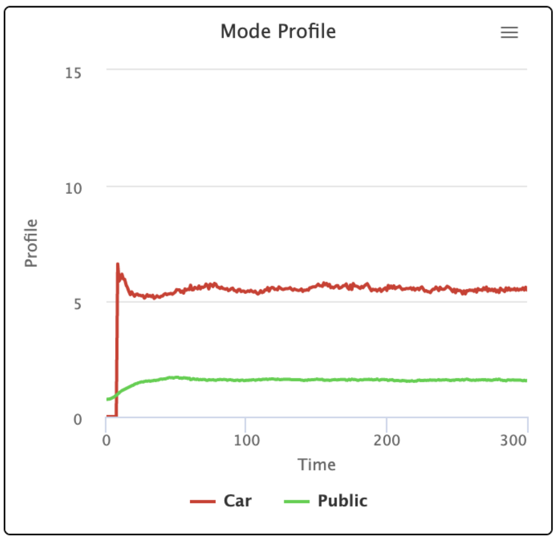
Combination 5.

Table 9



# of cars	# of public
565	2704

Table 10



Car Profile	Public Profile
5.481	1.568