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Sensitivity Analysis Of The Transportation Decision

MIEIC | Systems Modelling and Simulation

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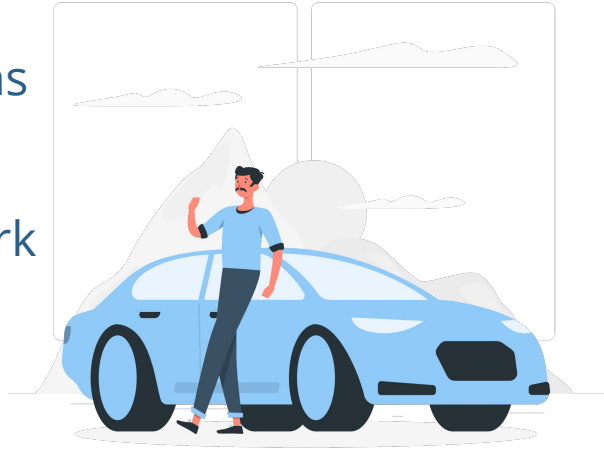
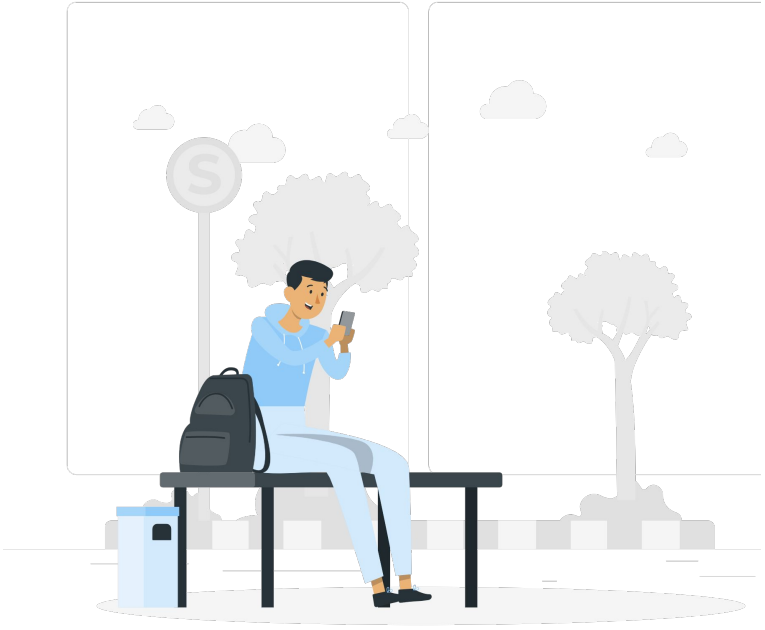


Introduction

Modern transportation is split in two main categories: **private** and **public** transportation.

Private transports

- owned by an individual and used for his/her needs;
- have a relatively low capacity;
- owner can freely choose the route to the destination.



Public transports

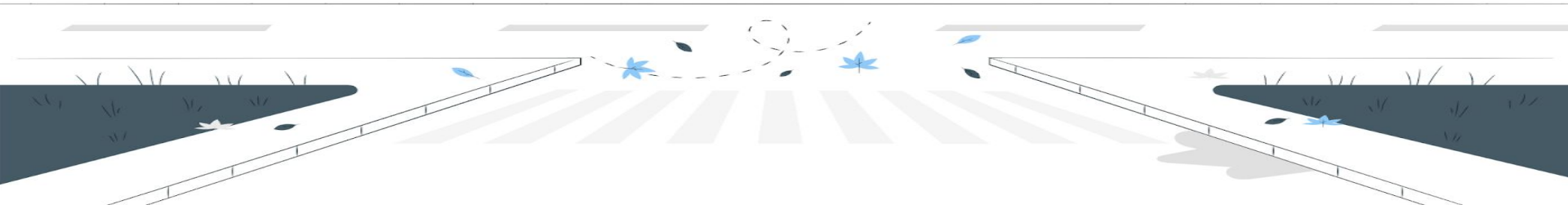
- managed by a third-party;
- have a big capacity;
- have a predefined route.

Motivation and Goals

Public transportation is getting cheaper but the general tendency remains that private transportation is the majority.

Cost is not the main driver for the decision, thus there are other variables that need to be factored in.

Factor the most variables possible and run a sensitivity analysis of the system



Input and Output Variables

Input Variables

- Number of private and public transports
- Number of commuters
- Bus capacity
- CO_2 emissions per transport
- Transports speed limitations
- Public transports average waiting time
- Fuel prices
- Ticket prices
- Road's length

Output Variables

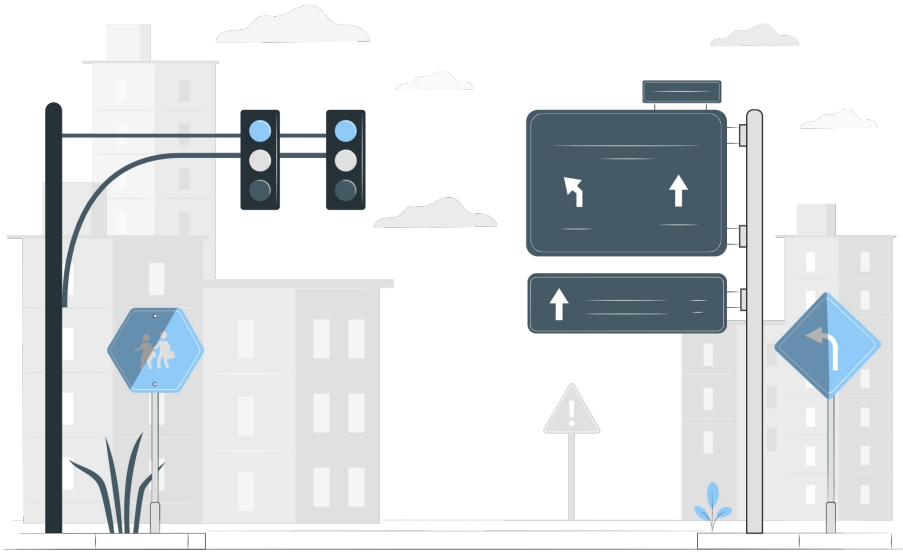
- Average travel time
- System's CO_2 emission
- Chosen transportation utility
- Commuters chosen transportation percentages
- Average transportation costs

Scenarios

In order to ascertain the influence of the different factors/parameters when deciding which transport to use, **different scenarios will be compared**:

- Variation in road's length
- Variation in the price of bus tickets
- Variation in fuel prices
- Variation in public transports average waiting time
- CO_2 emissions per transport

In all scenarios there will be **very significant decrease or increase in the parameter to be considered**, so it is possible to study in detail the weight of each parameter in decision making.



Cognitive Model

- Since agents need to make decisions, and in order to have a choice based on past experiences to simulate reality, it was necessary to implement a cognitive model.
- **Reinforcement learning** was used based on the Exploration–Exploitation trade-off dilemma.
- To do so, a 2-armed bandit problem was implemented, in which agents make choices according to the knowledge they acquired throughout the iterations, thus making a choice that maximizes their preferences and minimizes their total cost.

A simple bandit algorithm

Initialize, for $a = 1$ to k:

$Q(a) \leftarrow 0$

$N(a) \leftarrow 0$

Loop forever:

$$A \leftarrow \begin{cases} \operatorname{argmin}_a Q(a) & \text{with probability } 1-\varepsilon \quad \text{(breaking ties randomly)} \\ \text{a random action} & \text{with probability } \varepsilon \end{cases}$$

$R \leftarrow bandit(A)$

$N(A) \leftarrow N(A) + 1$

$Q(A) \leftarrow Q(A) + \frac{1}{N(A)}\left[R - Q(A)\right]$

Objective Function

- Two objective functions were used: one for the **public transportation** and another for the **private transportation**.
- The value of both objective functions depends on three parameters - **time, pollution and cost** - having as goal the minimization of them.
- **Public transportation objective function**:

$O_{PT}(T,P,C) = 2*T + P/2 + C/3$
T = 2*waitingTime + travelTime
P = system'sCO$_2$emissions
C = ticketPrice

- **Private transportation objective function**:

$O_{PT}(T,P,C) = 2*T + P/2 + C/3$
T = travelTime
P = system'sCO$_2$emissions
C = 2*tollFaresPrices + travelCost

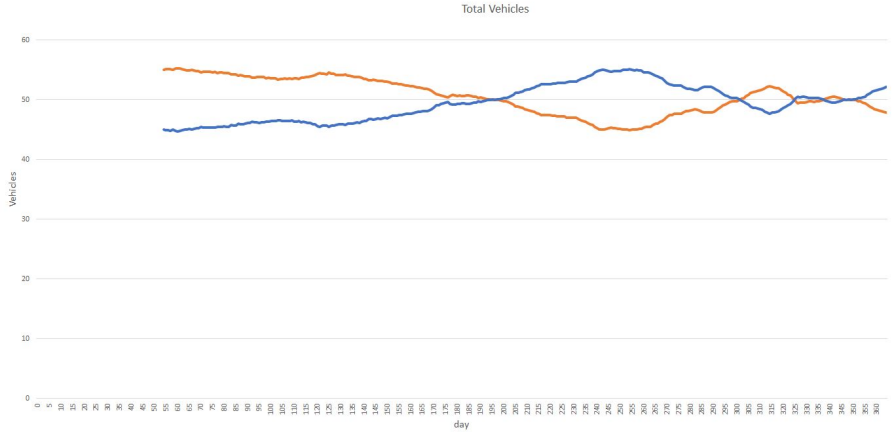
Demonstration

Let's take a look into the final result!

Results

- Default scenario

(1) Transportation choice (5km)



moving average(over 55 days) number of cars
moving average(over 55 days) number of buses

(2) Transportation utility (5km)

moving average(over 55 days) of car utility
moving average(over 55 days) of bus utility

Results

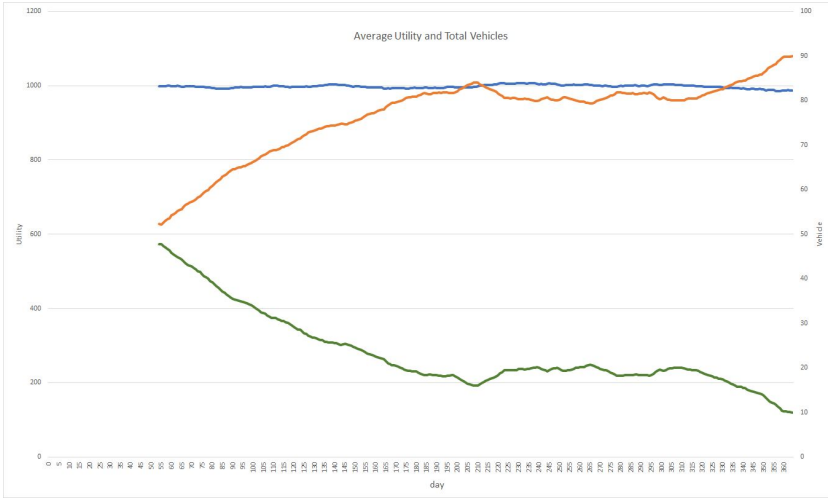
- Default scenario metrics

	Car	Bus
Average Travel time (s)	486	680
Average CO_2 emissions (mg)	116	103
Average Fuel consumption (ml)	498	443

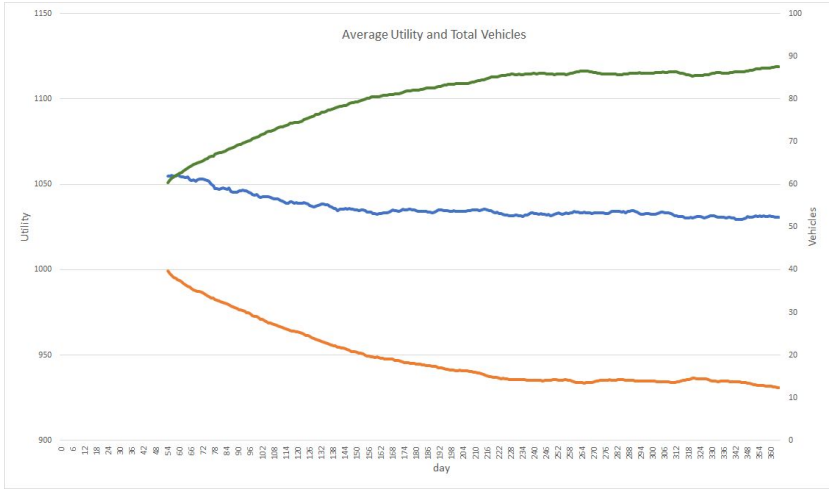
Results

- Variation in fuel prices

(1) Fuel price is 0 (€/liter)



(2) Fuel price is 5 (€/liter)



moving average (over 55 days) utility
moving average (over 55 days) number of cars
moving average (over 55 days) number of buses

Results

- Fuel price metrics variation

	Car (0€)	Car (5€)	Bus (0€)	Bus (5€)
Average Travel time	459	390	679	678
Average CO_2 emissions	113	86	100	100
Average Fuel consumption	498	368	428	428

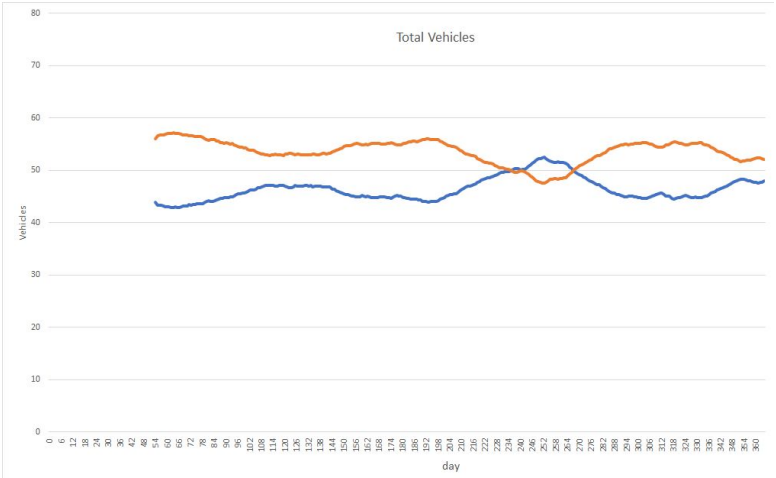
➔ With the decrease in the fuel's price, there is an increase of around **47%** in the number of people who start using private transportation. As such, the average travel time increased by **6%** due to increased road congestion.

➔ When the price of fuel increases, there is a decrease of **81%** in the number of cars used.

Results

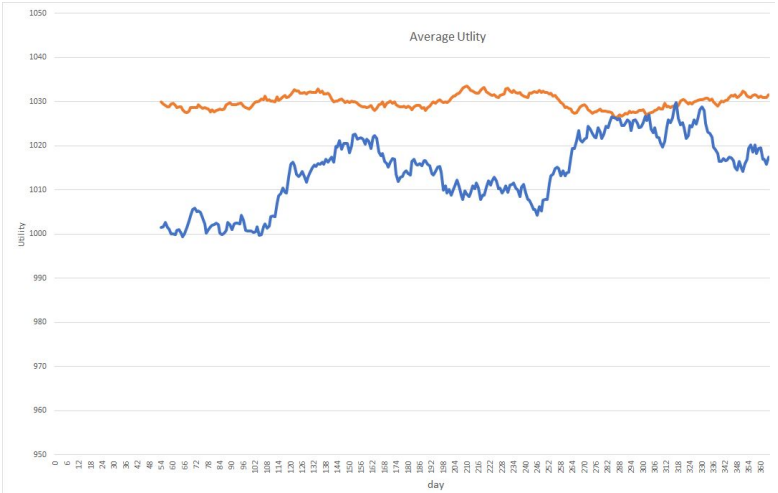
- Variation in the price of bus tickets

(1) Ticket price is 0€



moving average (over 55 days) number of cars
moving average (over 55 days) number of buses

(2) Utility



moving average (over 55 days) of car utility
moving average (over 55 days) of bus utility

Results

- Price of bus tickets (0€) metrics

	Car	Bus
Average Travel time	507	680
Average CO_2 emissions	117	104
Average Fuel consumption	504	448

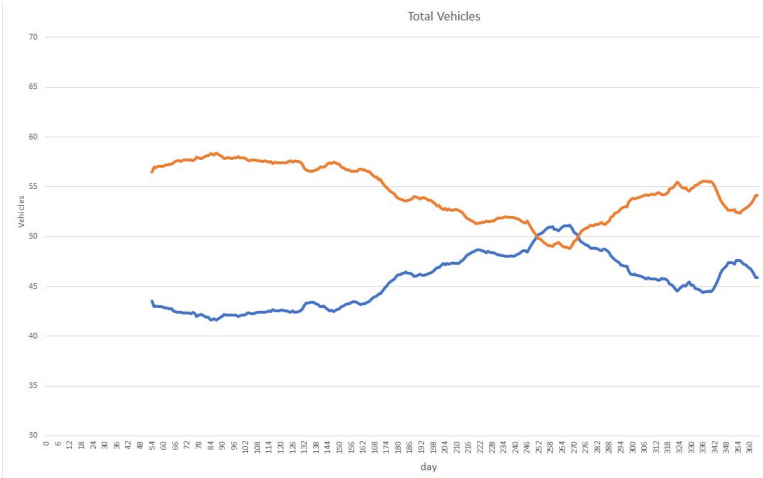
➔ The commuters' preferred mean of transportation was the **bus** by a small margin, having a slight increase in people using this transport.

➔ Although the fuel consumption and CO_2 emissions are bigger in this mean of transportation, the smaller average travel time is still a pivotal factor to the choice.

Results

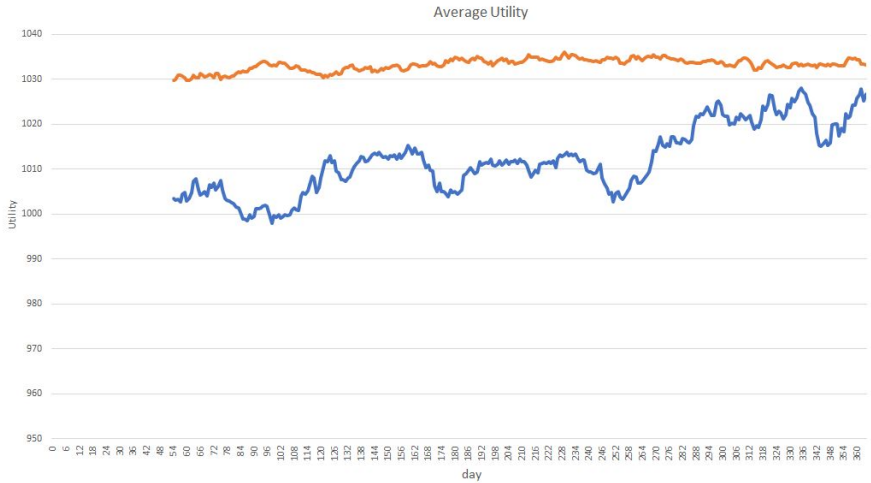
- Variation in the price of bus tickets

(1) Ticket price is 6€



moving average (over 55 days) number of cars
moving average (over 55 days) number of buses

(2) Utility



moving average (over 55 days) of car utility
moving average (over 55 days) of bus utility

Results

- Price of bus tickets (6€) metrics

	Car	Bus
Average Travel time	466	678
Average CO_2 emissions	111	100
Average Fuel consumption	476	433

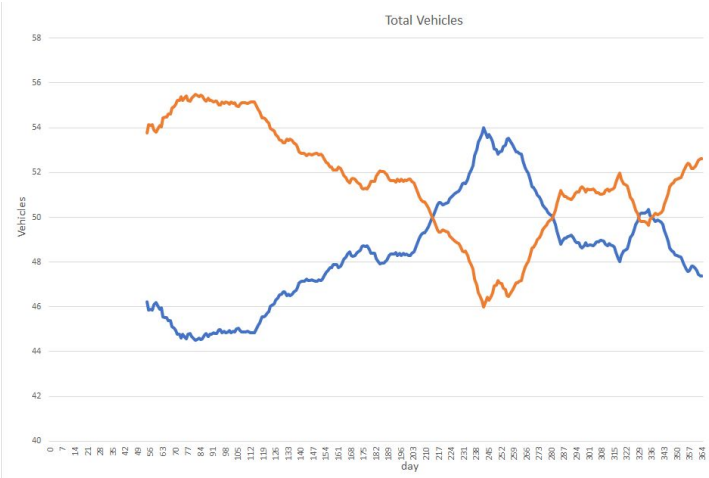
➔ The commuters' preferred mean of transportation was the **bus**, despite having a slight reduction of **2%** of people that used public transportation.

➔ The bus ticket reduced price is still appealing when compared to the usage of a car and its related consequences (fuel consumption and CO_2 emissions).

Results

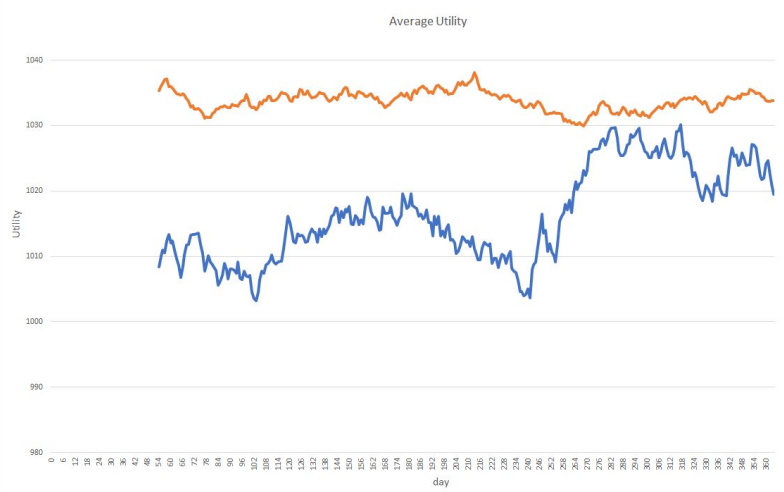
- Variation in the price of bus tickets

(1) Ticket price is 10€



moving average (over 55 days) number of cars
moving average (over 55 days) number of buses

(2) Utility



moving average (over 55 days) of car utility
moving average (over 55 days) of bus utility

Results

- Price of bus tickets (10€) metrics

	Car	Bus
Average Travel time	433	681
Average CO_2 emissions	105	102
Average Fuel consumption	452	438

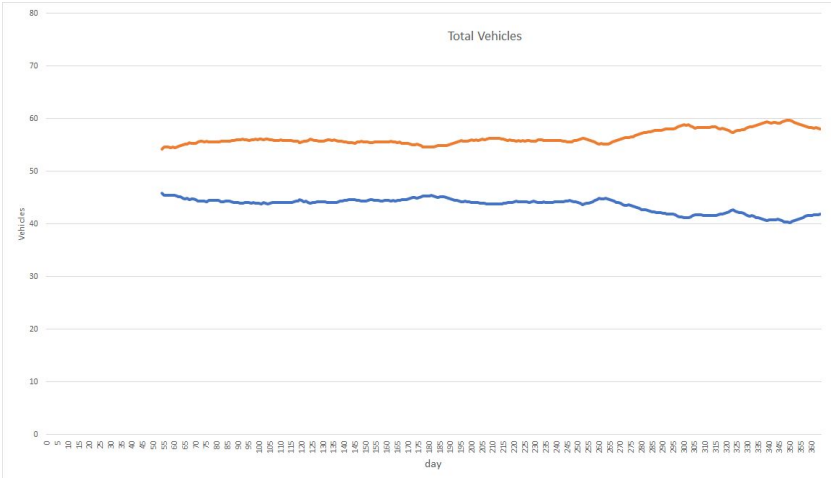
➔ The chosen transportation was **public transportation (bus)** by a margin of 7%. There was an increase of the usage in about 10%.

➔ There was also an increase from the previous scenario in which the bus tickets have a moderate price, which is contradictory.

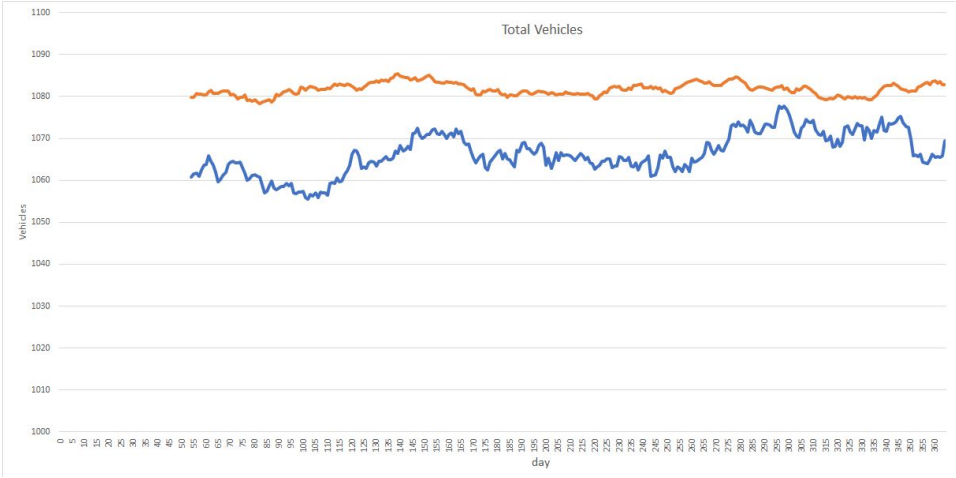
Results

- Variation in the CO_2 emissions per transport

(1) P emissions per transport



(2) Utility



moving average (over 55 days) number of buses
moving average (over 55 days) number of cars

Results

- P emissions metrics

	Car	Bus
Average Travel time	533	682
Average CO_2 emissions	117	102
Average Fuel consumption	503	438

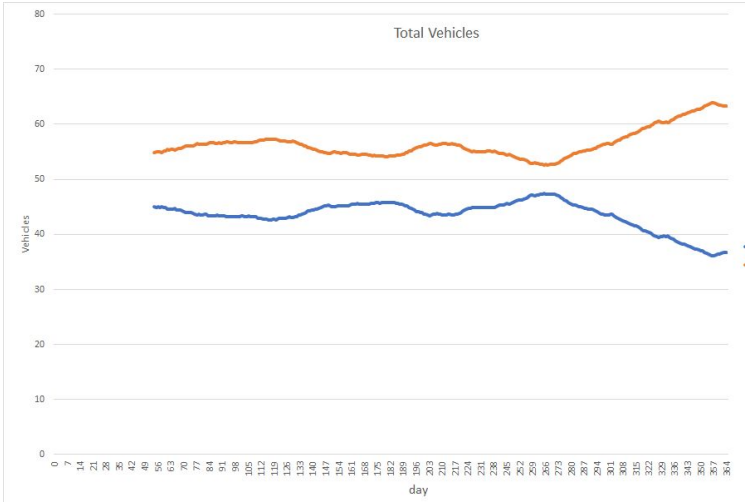
➔ When the weight of emissions is the double the default scenario, the number of users who choose the **car** as a means of transport decreases **10%**.

➔ **Public transportation (bus)** is the preferred mode of transport.

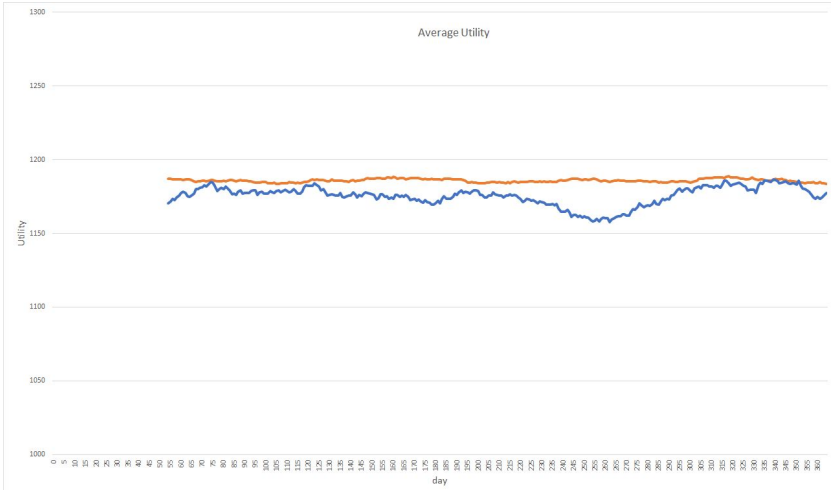
Results

- Variation in the CO_2 emissions per transport

(1) 2P emissions per transport



(2) Utility



moving average (over 55 days) number of buses
moving average (over 55 days) number of cars

Results

- 2P emissions metrics

	Car	Bus
Average Travel time	680	682
Average CO_2 emissions	117	102
Average Fuel consumption	503	439

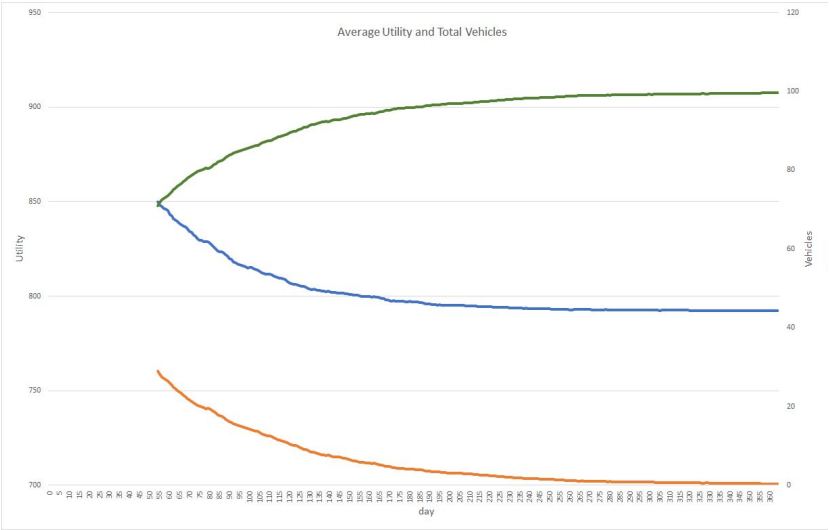
➔ When the weight of emissions is the quadruple the default scenario, the number of users who choose the car as a means of transport decreases **27%**.

➔ It is possible to observe a relationship between the decrease of the number of cars and the increase weight of emissions.

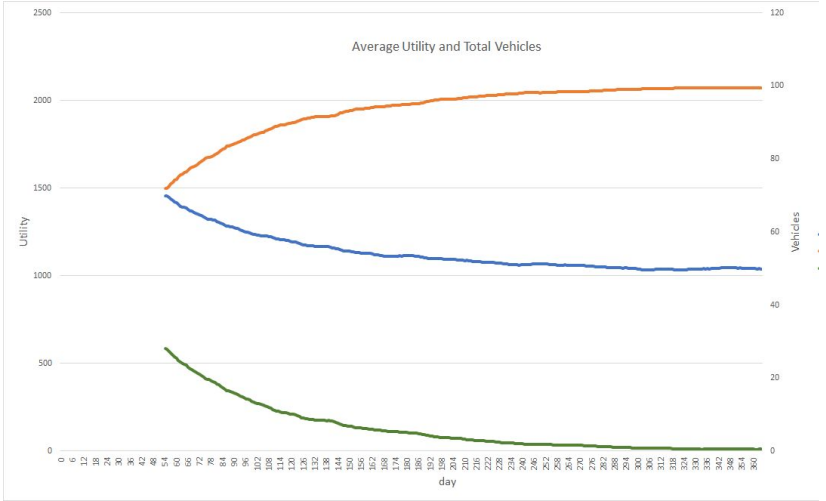
Results

- Variation in public transports average waiting time

(1) Waiting time is 1 minute



(2) Waiting time is 30 minutes



moving average (over 55 days) utility
moving average (over 55 days) number of cars
moving average (over 55 days) number of buses

Results

- Public transports average waiting time variations

	Car (1 min)	Car (30 min)	Bus (1 min)	Bus (30 min)
Average Travel time	-	439	681	-
Average CO_2 emissions	-	109	103	-
Average Fuel consumption	-	469	444	-

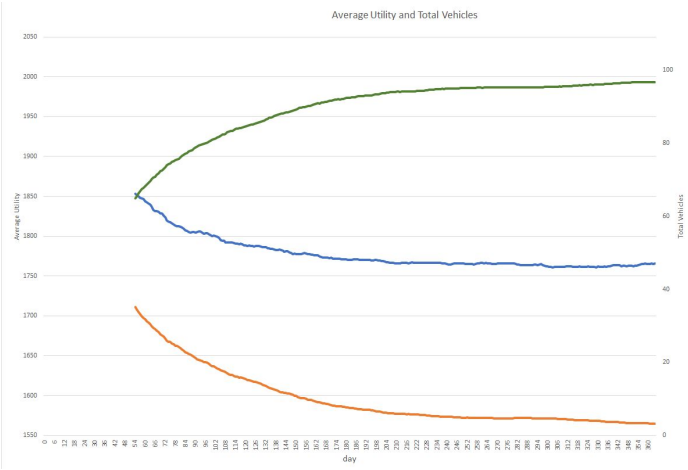
This scenario shows the enormous weight that public transports average waiting time has on the choice of commuters. When the waiting time is extremely high, all the commuters choose to travel by car. On the other hand, when having a waiting time close to 0, all commuters prefer to travel by bus.

Note: it is possible to observe that Car (30 min) metrics are strangely lower than the default scenario metrics. However, this can be explained due to SUMO variations and phenomena like the “accordion” effect (responsible for creating traffic congestion).

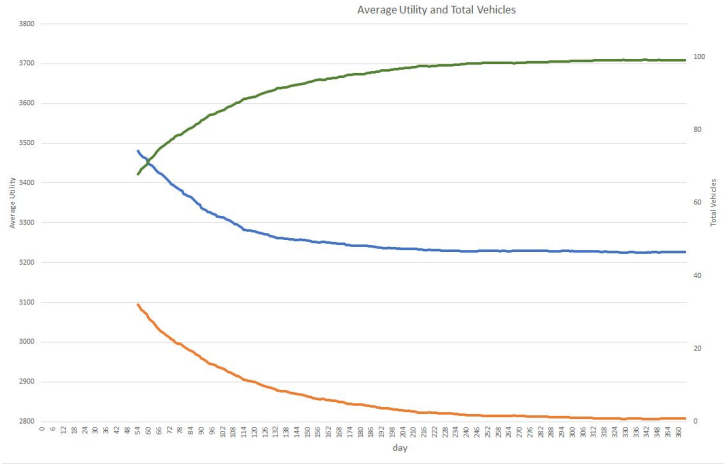
Results

- Variation in road's length

(1) 10km road



(2) 20km road



moving average (over 55 days) utility
moving average (over 55 days) number of cars
moving average (over 55 days) number of buses

Results

- Road's length metrics variation

	Car (10 km)	Car (20 km)	Bus (10 km)	Bus (20 km)
Average Travel time	865	1481	1361	2721
Average CO_2 emissions	175	294	203	404
Average Fuel consumption	691	1260	873	1740

The longer the road the more it will be spent on fuel, even though the travel time on bus is almost double than on car, agents preference for bus **increased by 92%**. It can be deduced that fuel cost is a big driver on the decision of the agents.

Conclusions

Agents are extremely sensitive to:

- Fuel cost
- Road length
- Waiting Time
- Emissions

Agents are easily influenced by the fluctuations of fuel prices. Accordingly longer travels require more fuel, thus agents are also sensitive to the length of the road.

Another factor that also heavily contributes to the decision is the waiting time. If public transport is has easily available as private transportation than more people would use it.

Finally, even though not has much, agents also showed some aversion to vehicle emissions.

Agents are not sensitive to:

- Ticket prices

Agents showed no significant change in option based on the variation of the ticket prices.

Future work

- ➔ Given the insensitivity of the agents to the variations of the bus ticket prices, the modulation of a Portuguese person's average income and transportation fees and expenses weight on their economies would be a good step to a more accurate simulation of this metric.
  - ◆ Fuel related intricacies were modeled in detail, while ticket prices were only represented by a single variable
- ➔ Run a sensitivity analysis while varying multiple input variables at the same time

Thanks

Illustrations credit: Storyset