Sensitivity analysis of the transportation decision

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***Abstract*—This document elaborates on the work developed for MSSI - Modelação e Simulação de Sistemas. The influence of the different decision factors for transportation method are not fully known. The paper expands on the evaluation methodology to analyze and detect the main drivers.**

During the development of this study, it was possible to provide commuters with a cognitive model that allowed them to make the most correct decision when choosing the means of transport to use. For this, Reinforcement Learning based on the Exploration–Exploitation trade-off dilemma was used. After simulating several scenarios, it was possible to perceive, with a high degree of confidence, the factors that most influence the decision-making of commuters.

Although the paper presented here elaborates on a large number of variables, it is important to point out that all analyzes were carried out individually, that is, varying only one at a time. For a better analysis and applicability to reality, it would be necessary to incorporate in the simulation the variability of multiple variables simultaneously.

The paper presents the initial foundations and concept in order to facilitate the expansion of the work and scenarios under analysis.

***Index Terms*—sensitivity, transports, system, decision-making**

I. Introduction

Modern transportation is split in two main categories: private and public transportation. Private transports are owned by an individual and used for his/her needs, having a relatively low capacity. Public transportation is managed by a third-party and has a big capacity.

While a private transport can freely choose the route to the destination, public transports have a predefined route. This is the main difference and deciding factor between them.

A. Motivation and Goals

Even though public transportation is getting cheaper the general tendency remains that private transportation is the majority. This implies cost is not the main driver for the decision, thus there are other variables that need to be factored in.

The goal of the project is to factor the most variables possible and do a sensitivity analysis of the system. Ultimately it is possible to infer the main drivers on the decision of the transportation. Policy makers are able to substantiate their positions and take better decisions.

B. Paper structure

The rest of this paper is structured as follows: Section II depicts the system to model and the respective input and output variables. Sections III and IV present, respectively, the hypothesis and the corresponding scenarios that will be studied. Section V contains all the details regarding the problem formalization: variables and respective domains, constraints, objective function and data visualization techniques. Section VI contains the assumptions made during the simulation. Section VII contains the model specification, namely variables' basis values and the cognitive model description. Following that, section VIII contains integration, logic and block diagrams that expand on the project's architecture. Section IX contains the simulation scenarios, section X explores the results of the simulation and section XI contains the related work. Lastly, section XII concludes this paper with the main achievements and findings, and future work.

II. System

The system models monetary, social and geographical variables [1]. The decision making and action taking processes is made using Reinforcement Learning based on a 2-bandit problem.

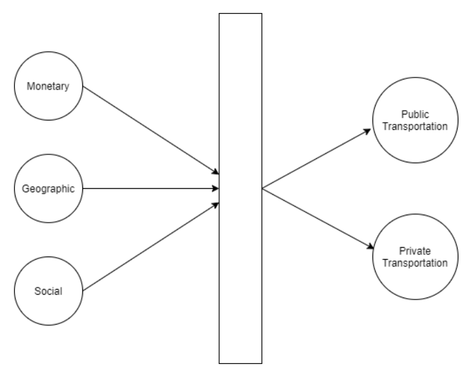


Fig. 1. High Level representation of the system

A. Inputs and Outputs 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 emissions
  - Commuters chosen transportation percentages
  - Chosen transportation utility
  - Average transportation costs [1]

III. Hypothesis

The theme of **public transport vs private transport** has long been debated and studied. Although it is known that the greater use of public transport contributes to a more sustainable planet, not all people are willing to give up the convenience and comfort of their private vehicles.

As such, our objective with this simulation was to draw conclusions about the behavior of the population based on some hypotheses that we wanted to be proven or disproved.

Only one parameter is varied, never 2 or more at the same time.

- **Bus tickets price**
  - When the ticket price is less than € 0.50, about 50% of commuters who used private transportation will switch.
  - On the other hand, if this value goes up to double or triple the usual (2 €), 25% of the people who use the bus will look for the other alternative
- **Fuel price**
  - Reducing the price of fuels to half of what is currently practiced, will make 20% of commuters who use buses prefer to use a car.
  - If the values go up, it is expectable that after a certain margin of acceptance, more than 25% of people prefer to switch to public transportation.
- **Waiting time**
  - Cutting the waiting time of users at bus stops by half would allow 30% of users using private transport to make the transition.

IV. Scenarios

This section addresses the different scenarios that were target of evaluation throughout the simulation.

[1]This value is not an individual output variable, but rather reflected in the Utility's output value.

In order to ascertain the influence of the different factors/parameters when deciding which transport to use, different scenarios were compared. For this, it is necessary to define a default case, which serves as a basis for comparison. This scenario presents values appropriate to the environment in which it operates, that is, the price of fuels, tolls and tickets are similar to the prices that are practiced in Portugal.

Each scenario presented below contains a variation of extremes, in other words, there is a very significant decrease or increase in the parameter to be considered.

- **Variation in the price of bus tickets**
  - There was a comparison against the default scenario of what happens when the ticket price is 0 and the same when the value is three times the usual value. In this way, it was possible to identify and perceive certain behavioral patterns and understand the extent to which price is a key factor in this decision making.
- **Variation in fuel prices**
  - Variation associated with private transportation, more specifically in fuel's price. This variation intends to study how private drivers reacted and what degree of variation they support, that is, the maximum amount they are willing to spend on fuel to avoid having to use buses.
- **Variation in road's length**
  - Variation associated with both modes of transport, where the size of the roads to be covered was changed. In this way, by varying the length of the road, factors such as cost, time and emissions were also affected, and in this way it was possible to study in detail the weight of each parameter in decision making.
- **Variation in public transports average waiting time**
  - Variation associated with public transportation, more specifically the average time a commuter has to wait for its transport. This variation intends to identify the maximum time that commuters that usually travel in public transports are willing to wait for the transportation to avoid using their own car.
- **CO_2 emissions per transport**
  - Scenario to compare how CO_2 emissions affect each transportation mode. It was possible to identify and perceive how this affects both the public and the private transportation and to what extent it is a key factor in the commuter's decision-making process.

V. Formalization

A. Variables and respective domains

The system is composed by the overall following input variables:

- **Number of public transports**: integer value
- **Number of private transports**: integer value
- **Number of commuters**: integer value

The public transportation is also characterized by the following variables:

- **Ticket price**: float value used to express a price, in euros (€).
- **Public transports' average waiting time**: integer used to express time, in seconds.

The private transportation also have specific variables such as:

- **Fuel prices**: float value used to express a price, in euros (€).

Besides these variables, both transportation modes are affected by:

- **CO_2 emissions per transport**: integer value used to express the amount of CO_2 emitted, in mg/s.
- **Speed limitations**: integer value used to express a velocity, in m/s.

There are also input variables related to the road the transports move on:

- **Road's length**: integer value used to express a size, in kilometers (km).

Finally, there are the following output variables:

- **Average travel time**: integer used to express time, in minutes.
- **System's CO_2 emissions**: integer value used to express the amount of CO_2 emitted, in g/km.
- **Average transportation costs**: float value used to express the price, in euros (€)
- **Chosen transportation utility**: float value used to express the utility, in unities.
- **Commuters chosen transportation percentages**: float value used to express a percentage.

B. Constraints

The work developed has some constraints regarding the environment in which the simulations occurs:

*1) **Number of roads**:* Existence of only two roads, one for public transportation and other for private.

*2) **Origin and arrival points**:* The commuters all have the same start and end point for all trips executed.

*3) **Values of the inputs**:* The values of the input variables, such as speed, prices, etc., are based on the values currently applied in Portugal.

C. Objective Function

In this project two different objective functions are used: one for the commuters that travel in public transportation and another for the ones that travel in private transportation. The value of both objective functions depends on three parameters - time, pollution and cost - and the goal is to minimize both of them.

$$ObjectiveFunction = O(Time, Pollution, Cost)$$

Public Transportation

$$O_{\mathrm{PT}}(T, P, C) = 2 * T + P/2 + C/3$$
$$T = 2 * waitingTime + travelTime$$
$$P = system'sCO_2emissions$$
$$C = ticketprice$$

Private Transportation

$$O_{\mathrm{PR}}(T, P, C) = 2 * T + P/2 + C/3$$
$$T = travelTime$$
$$P = system'sCO_2emissions$$
$$C = 2 * tollFaresPrices + travelCost$$
$$travelCost = travelDistance * fuelConsumption * fuelPrice$$

D. Data Visualisation Techniques

Tables and graphs were used to view the results of each simulation ran in order to provide an intuitive way of analysing the results and easily take conclusions about them.

VI. Assumptions

During the simulation the following assumptions were made:

- The capacity of private transport is 1 passenger
- All commuters start and end at the same point of departure and arrival, respectively
- The travel time between the commuter house and the starting point is ignored
- There is only one bus stop, located at the starting point
- The time for passengers to enter the bus is 0
- 1 single road per transport type

VII. Model specification

A. Variables' basis values

In the previous section, II. A., the variables that would be part of the Simulation System, both Input and Output, were addressed.

In this section, the domain of the **Independent variables**, that is, the Input variables, will be **deepened**.

In order to make the sensitivity analysis as realistic as possible, the values used in the independent variables are similar to the values practiced in Portugal.

With this, it is intended to analyze and study the behavior of the Portuguese population in reaction to different scenarios.

As such, the following values were assumed as the **basis for each of the input variables** of the simulation system, the value of which was varied during the execution of the scenarios.

*1) **Number of private and public transports**:* Refers to the number of transports that were in circulation during the Simulation.

$$\textit{No. Public Transp.} = 30$$

$$\textit{No. Private Transp.} = 200$$

*2) **Number of commuters**:* Number of commuters who make decisions during the simulation.

$$\textit{No. Commuters} = 100$$

*3) **Bus capacity**:* Maximum capacity of each Bus.

$$\textit{Capacity} = 30$$

*4) **CO_2 emissions per transport**:* Value that affects the perception of commuters in a social component, and that may influence their future choices.

$$\textit{Emissions Public Transp.} = 0,03mg/s$$

$$\textit{Emissions Private Transp.} = 0,05mg/s$$

*5) **Transports speed limitations**:* Speed with which the transport moves and determines the travel time between the point of departure and arrival.

$$\textit{Speed Public Transp.} = 8m/s$$

$$\textit{Speed Private Transp.} = 16m/s$$

*6) **Public transports average waiting time**:* Only applied to public transport. It reflects the time interval between the passage of buses. This value follows a normal distribution.

$$\textit{Avg. waiting time} = 300s$$

*7) **Fuel prices**:* Value that only influences private transportation.

$$\textit{Fuel price} = €1.50$$

*8) **Ticket prices**:* Value that only influences public transportation.

$$\textit{Ticket price} = €2.00$$

*9) **Road's length**:* Value that affects both transports.

$$\textit{Road length} = 5km$$

B. Cognitive Model description

The simulation system Agents have to make decisions regarding the type of transport to use to move from origin to destination. As such, it was necessary to implement a **Cognitive Model** that allows them to make these decisions in order to achieve their goals, taking into account past experiences and the different types of variables to which the agent is subject (monetary, social and geographical).

In order for the agents' decisions to be as real as possible, **Reinforcement Learning** is used based on the Exploration–Exploitation trade-off dilemma.

In order to make this possible, Agents take into account an **Objective Function**, which may or may not vary from Agent to Agent taking into account the input variables of the system.

After each iteration, the Agent updates its value in the table, and have it as a reference in the following iterations. Through Reinforcement Learning, the Agent is able to understand over time what type of transport to use. The goal is for each agent to make the decision that meets their goals (lowest value).

Since a model with a single starting point was used, the Table only has one **State**. As far as **Rewards** are concerned, their value is equal to the value of the Objective Function after the Agent performs a certain **Action**. Note that the Action refers to the choice between Public and Private transportation.

To create the Agent's cognitive model, a 2-armed bandit problem was used, in which agents make choices to try to maximize the gains from their action.

Since the approach follows an exploration-exploitation dilemma, it was necessary to assign an exploration rate to each Agent. This exploration rate is reduced throughout the simulation through a multiplicative function. This is because over time the Agent wants to stop exploring the actions and start taking advantage of the knowledge that was obtained over time (exploitation).

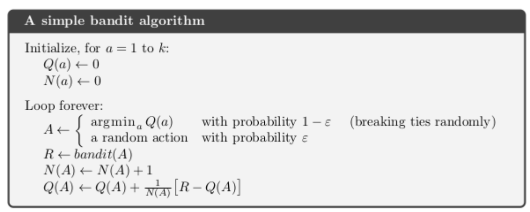
Below is the formulation of the 2-armed bandit problem followed.

Being:

ϵ = exploration rate

R = utility value after action performance

Q(A) = known utility value for action A, present in the Agent's table



A simple bandit algorithm

Initialize, for $a = 1$ to k:

$Q(a) \leftarrow 0$

$N(a) \leftarrow 0$

Loop forever:

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

$R \leftarrow bandit(A)$

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

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

Fig. 2. Bandit Algorithm

VIII. Diagrams

This section expands on the details of the project's architecture, from top to bottom.

A. Integration diagram

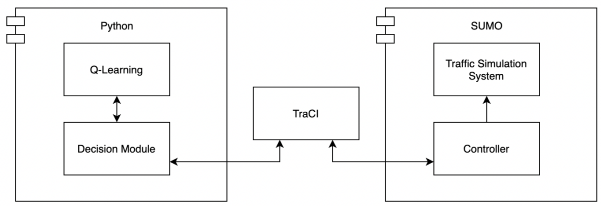


Fig. 3. Integration Diagram

The connector between the decision module and **SUMO** is *TraCI* - "**Tra**ffic **C**ontrol **I**nterface" [2]. It exposes a TCP/IP server, being agnostic to the programming language used to develop the module. Python was chosen due to having a vast library of existing packages [3] and also allows for faster development.

B. Logic diagram

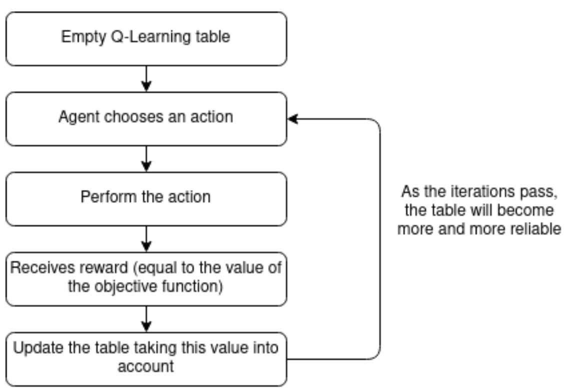


Fig. 4. Internal logic diagram

The decision process is based on a tabular **Bandit problem** which aims to replicate how human beings act. Each iteration serves as feedback, thus allowing agents to improve and take better and better decisions.

C. Block diagram

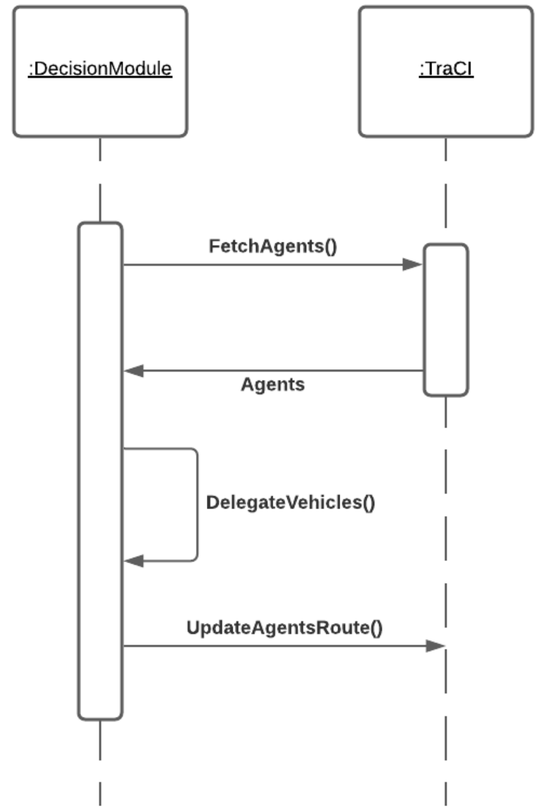


Fig. 5. Decision Module and TraCI Interaction

The **Decision Model** consists of a loop that *fetches* the agents and runs the decision logic on each of them. *DelegateVehicles* takes the agents and the environment into consideration and using a Exploration-Exploitation based approach it delegates the vehicles. Having the final decisions being made, the results are uploaded to *TraCI*. On the next iteration, the loop repeats taking into consideration the outputs of the simulation.

IX. Simulation scenarios

Each run of the system simulates a year[2], in order to allow it to stabilize. The results of the previous day are the input to the **Cognitive Model** engine.

[2]365 days

X. Results and Analysis

All presented plots in this section were drawn using a moving average over a period of 55 days (15% of the total number of days).

A. Default Scenario

The default scenario consists of a **5 km road** with two lanes, one for private vehicles (car) and another for public transports (bus). A simulation was ran over a period of a year and the results were collected and set as the baseline for any future simulations. The **blue line represents the results for the cars** and the **orange one the buses**.

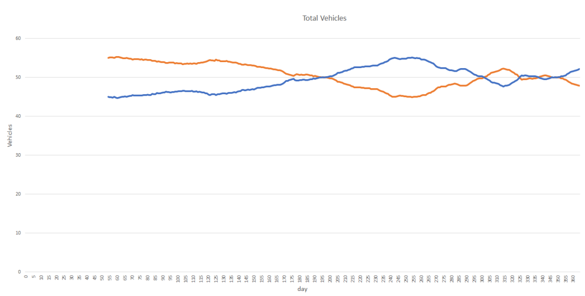


Fig. 6. 5 km road transportation choice

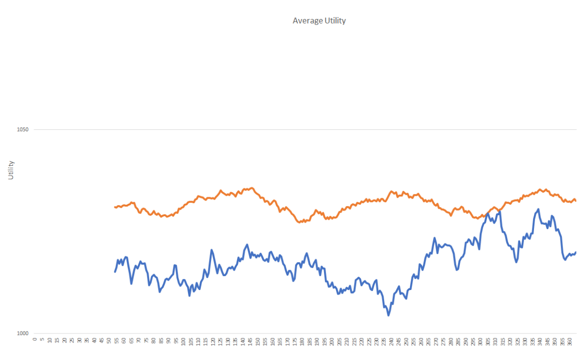


Fig. 7. 5 km road transportation utility

TABLE I
Default Scenario Metrics

	Car	Bus
Average Travel Time	486	680
Average CO_2 Emissions	116	103
Average Fuel Consumption	498	443

The travel time of thus bus was **150% higher** than the car, due to the fact it has lower speed limits. The emissions and fuel consumption were close due to the fact they've ran the same distance [3].

[3]akasdkjfl

B. Variation in fuel prices

The objective was to analyze how commuters' decision-making varies with the increase and decrease of fuel prices. As such, **two new simulations** were run, one where the *fuel was free* and the other where this *price was 5 €/liter*.

Below are two plots that show how commuters' decision making varies over the simulation (365 days). The **green line represents the moving average of the use of buses**, the **orange the moving average of the use of cars**, and finally, the **blue one is the moving average of the utility average**.

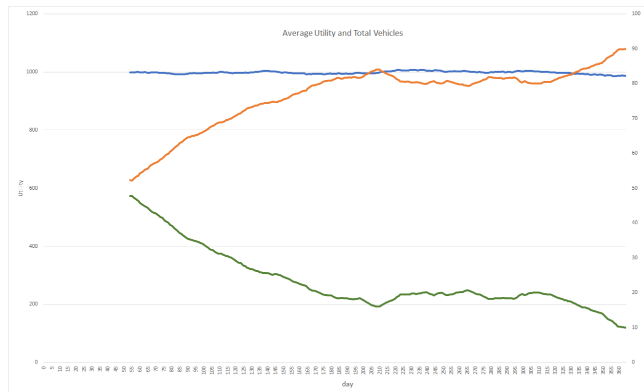


Fig. 8. Fuel price is 0 (€/liter)

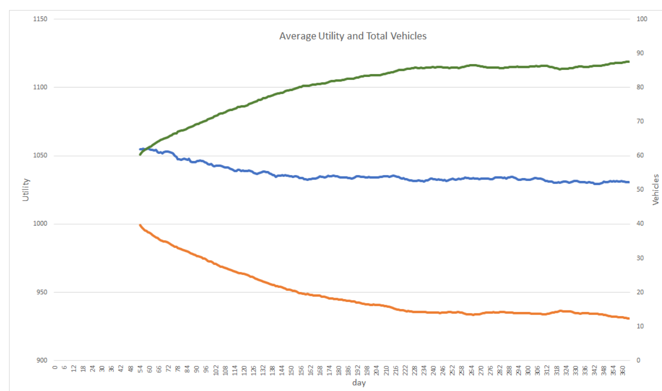


Fig. 9. Fuel price is 5 (€/liter)

It was also possible to collect, through the simulations, the following set of values.

	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

It is possible to verify that when the price of fuel is 0€, there was a **47% increase** in people using private transport, as such the network became more congested and the average travel time **increased by around 6%**. In the case where the price of fuel rose to 5 € per liter, the opposite happened, the number of car users when compared to the default scenario **decreased by around 81%**.

C. Variation in bus tickets price

This scenario reflects the difference that the public transportation ticket prices would make in the system. **Different bus ticket prices** were introduced in each simulation: **0€, 6€ and 10€**. These prices reflect the best possible price, an average one and an expensive ticket price. Below, there are plots that show how commuters' decision making varies over the simulation (365 days). The **blue line represents the moving average of the use of cars/car usage utility** and **the orange the moving average of the use of buses/bus usage utility**.

1) Ticket price is 0€

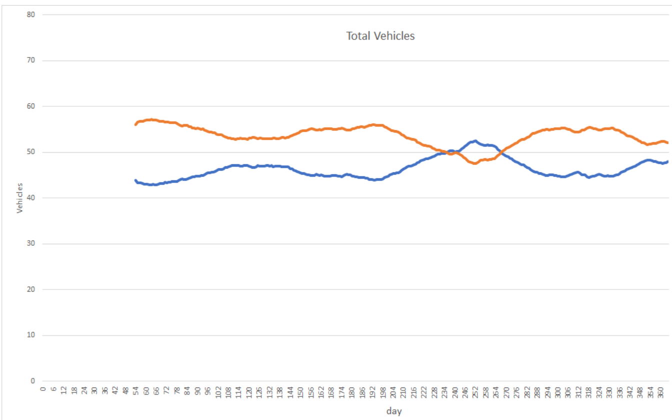


Fig. 10. Ticket price is 0€ (Transportation choice)

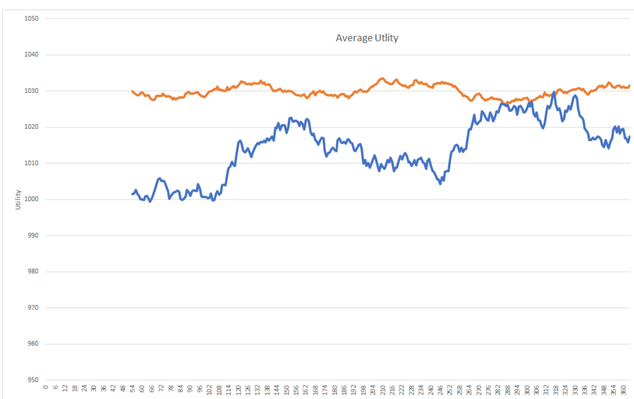


Fig. 11. Ticket price is 0€ (Utility)

TABLE II
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. All of the factors (fuel consumption, CO_2 emissions and total cost) support this choice, except for the fact that the Average Travel Time (about **1.5x the average travel time of private transportation**) that contributes to the balance of the utility between both transportation means. This is the expected result, however **the discrepancy between both transports should be bigger**, given the advantage of having a trip with no costs involved.

2) Ticket price is 6€

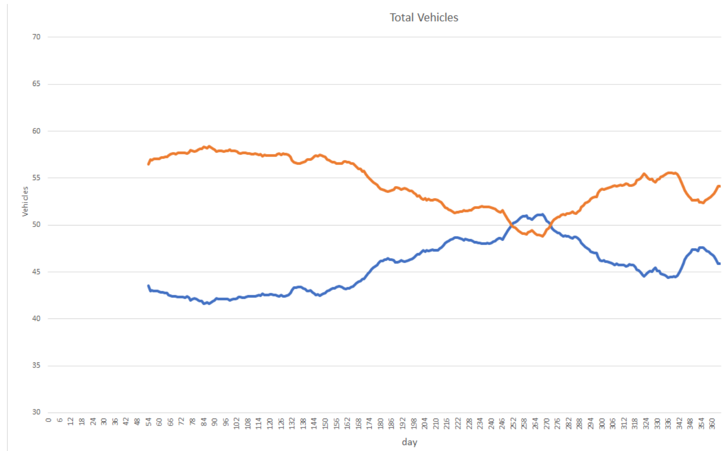


Fig. 12. Ticket price is 6€ (Transportation choice)

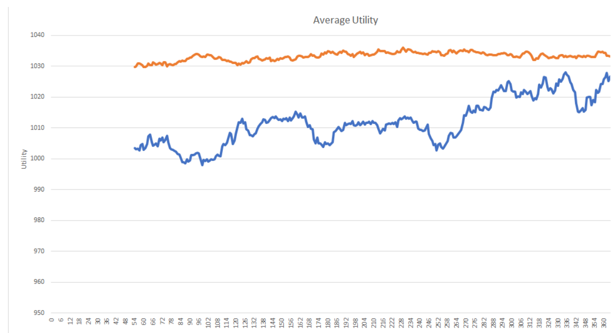


Fig. 13. Ticket price is 6€ (Utility)

TABLE III
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).

There was also an **increase from the scenario in which the bus tickets have no price, which is contradictory**.

3) Ticket price is 10€

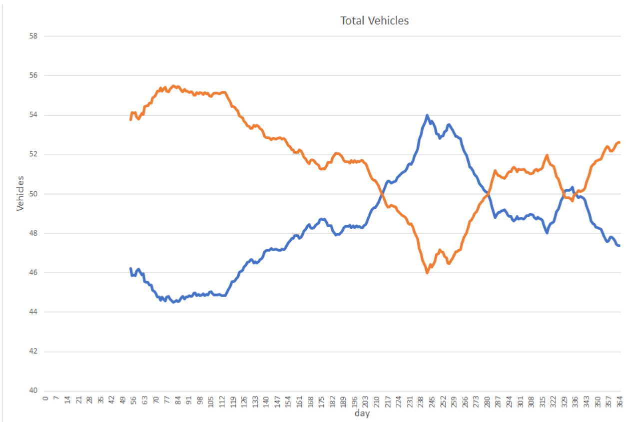


Fig. 14. Ticket price is 10€ (Transportation choice)

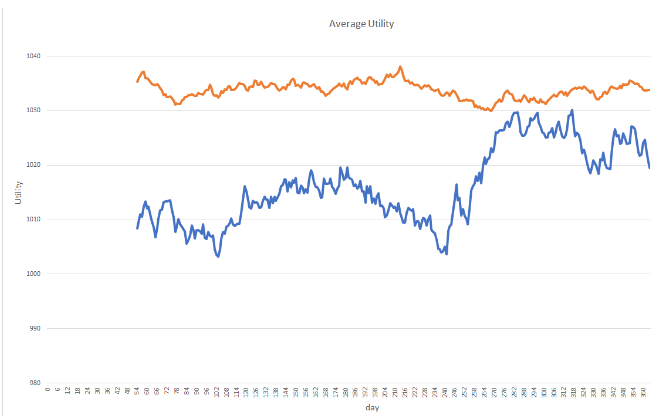


Fig. 15. Ticket price is 10€ (Utility)

TABLE IV
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, possibly indicating a bad modelling of the ticket price and its influence to the objective function.

D. Variation in the CO_2 emissions per transport

This scenario reflects the difference that different weights of CO_2 emissions of both transportation means in the sub-section V-C (Formalization - Objective Function) make in the commuters decisions. While the CO_2 emissions of each transport type are constant, its weight on the objective function might lead the commuters to different actions. Different weights were introduced in each simulation: P and 2P, having as reference value P/2 of the default simulation, meaning that the weight on the objective function is be doubled and quadrupled respectively in each scenario. Below, there are plots that show how commuters' decision making varies over the simulation (365 days). The **blue line represents the moving average of the use of cars/car usage utility** and the **orange the moving average of the use of buses/bus usage utility**.

1) P emissions per transport

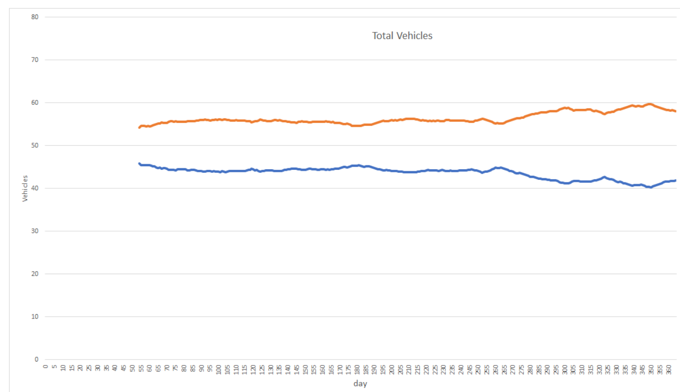


Fig. 16. P emissions per transport (Transportation choice)

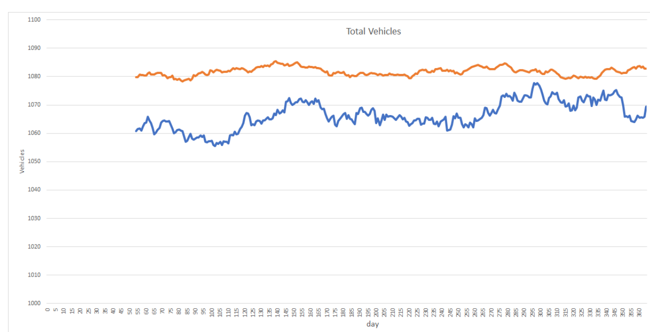


Fig. 17. P emissions per transport (Utility)

TABLE V
P EMISSION METRICS

	Car	Bus
Average Travel Time	533	682
Average CO_2 Emissions	117	102
Average Fuel Consumption	503	438

The chosen transportation was the **public** one (bus). When the weight of emissions **doubles** the value on the default scenario, the number of users who chooses the car as a mean of transport **decreases 10%**. This also implies a strong link between commuters and **environmental awareness**.

2) 2P emissions per transport

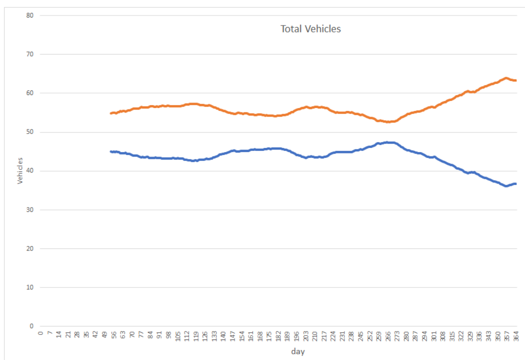


Fig. 18. 2P emissions per transport (Transportation choice)

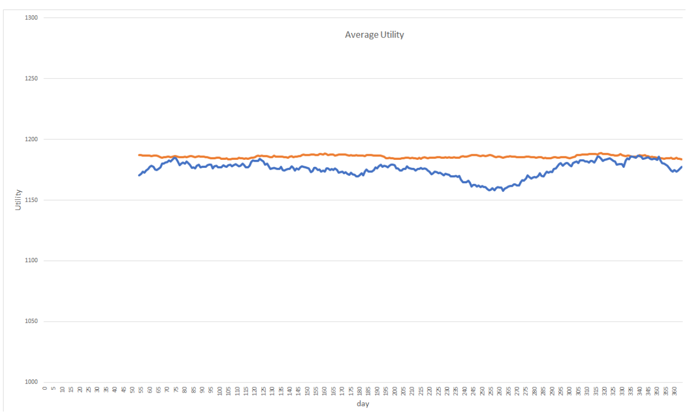


Fig. 19. 2P emissions per transport (Utility)

TABLE VI
2P EMISSION 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 mean of transport decreases 27%** making **public transportation the most used transportation type**. This scenario makes the relationship between the **decrease of private transportation usage and the increase of the weight of CO_2 emissions** clearly observable.

E. Variation in public transports average waiting time

The objective of this study scenario was to analyze the influence of the **public transports average waiting time** on the commuters' decision-making. As such, two new simulations were run, one where the waiting time was **1 minute** and the other where this time was **30 minutes**. Below are two plots that show how commuters' decision making varies over the simulation (365 days). The green line represents the moving average of the use of buses, the orange the moving average of the use of cars, and finally, the blue one is the moving average of the utility average.

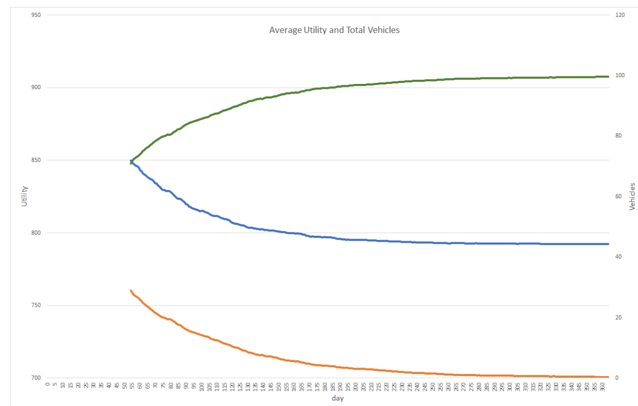


Fig. 20. Waiting time is 1 minute

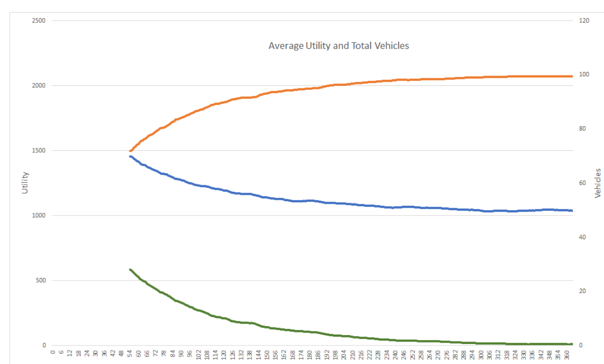


Fig. 21. Waiting time is 30 minutes

It was also possible to collect, through the simulations, the following set of values:

	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 commuters' decision making**. When the waiting time is extremely high, i.e., 30 minutes, **all the commuters choose to travel by car** and, on the contrary, having a waiting time of 1 minute makes **all commuters prefer to travel by bus**.

On a final note, it is possible to observe that the car metrics for the 30 minutes waiting time 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).

F. Variation in road's length

This scenario explored the influence of the road length (total distance to travel) in the decision of means of transportation. Two scenarios were tested: **10 km road** and a **20 km road**, a two times and four times increase, respectively. The simulation results, over a period of 365 days, are displayed below. In **blue there's the average utility**, in **green there's the total number of bus** and in **orange the total number of cars**.

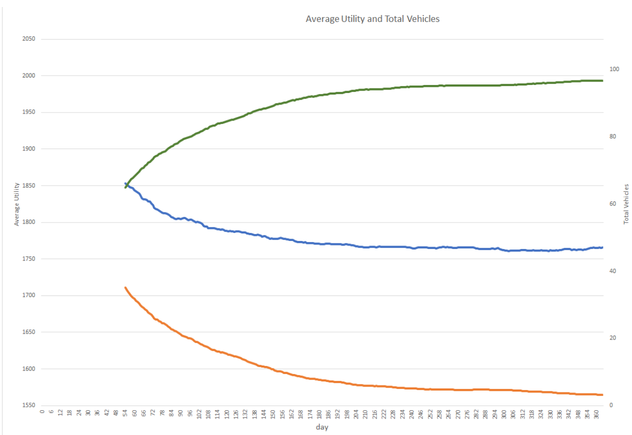


Fig. 22. 10 km road

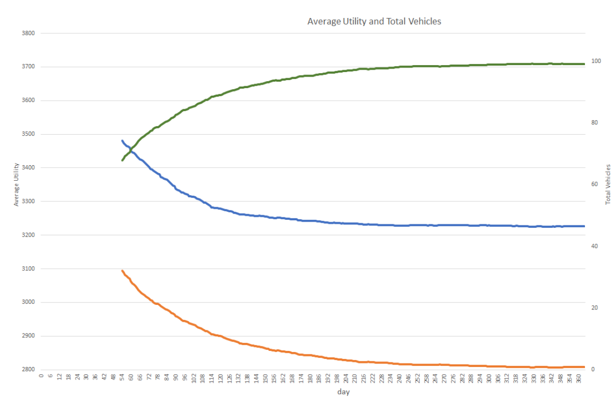


Fig. 23. 20 km road

	Car (10 km)	Car (20 km)	Bus (10 km)	Bus (20 km)
Average Travel Time	865	1481	1361	2721
Average CO2 Emissions	175	294	203	404
Average Fuel Consumption	691	1260	873	1740

In both cases **all agents migrated** to use **bus only**. Even though the travel time of the buses is **150%-200% higher than the cars**, commuters are extremely sensitive to *fuel consumption*. For longer distances the cost of the ticket is much more appealing. This exposes another characteristic of small travels, the **convenience factor** [4].

XI. Related Work

Kokkinogenis, Monteiro and Rossetti [1] approach network modelling for different transportation types by attributing an individual route for each transportation type. This bi-modal network allows greater simplicity not only in terms of modelling but also to the characterization of each route. Also, the only agent introduced into the system are commuters. Each agent will then be defined by a set of state variables such as desired departure and arrival time, experienced travel time, etc. which will be evaluated by the agent itself contributing to its decision making and adapting. The scenario in which the simulation happens has a time interval of 3 hours and on the end of each execution, according to each commuter's input on time, cost, crowding level and polluting gas emissions, the following day's utility will be calculated. This utility will be pivotal into the agent's decision on which transportation type to choose.

In the presented paper, some of the previous aspects were kept, while others were refined. Both the bi-modal network modelling and the commuters as the only agent in the system were maintained. As for the scenario, the considered iteration time interval lasts 24 hours and the simulation encapsulates a total of 365 days/iterations. The utility function has slight changes as mentioned in sub-section V-C (Formalization - Objective Function), however, the main principle is kept: the agent receives the inputs of the current iteration of the simulation with the objective of the selection of the best option for the following day.

XII. Conclusions

A. Main achievements and findings

It was shown that the transportation decision is highly influenced by fuel cost, road length, waiting time and 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. Even though not has much, agents also showed some aversion to vehicle emissions.

On the other hand, ticket prices don't seem to have influence in the commuter's decision making as the agents showed no significant change in option based on the variation of the ticket prices.

Concluding, the project turned out very complete and allowed to draw robust conclusions regarding the commuter's decision making. Besides that, as the project is highly scalable, it can easily be upgraded to represent more complex systems in the future.

[4] It's much more convenient to use the own car for small distances

B. 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. The modulation of fuel related intricacies were done with good detail, depending on multiple variables while the bus ticket prices depended on a single variable. This is another option for its modulation without having to increase the system's complexity.

The fact that each scenario only explored one input variable means that changes were studied isolation which does not easily translate to real life. The next step would be to run a sensitivity analysis while varying multiple input variables at the same time, studying how the multiple variables inter-operate and influence each other.

REFERENCES

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