Sensitivity analysis of the transportation decision

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***Abstract*—This document elaborates on the problem formalization 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.**

***Index Terms*—sensitivity, transports, system, congestion**

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'll be possible to infere the main drivers on the decision of the transportation. Policy makers will be able to substantiate their positions and take better decisions.

II. System

The system will model monetary, social and geographical variables [1]. The decision making and action taking processes will be made using Reinforcement Learning based on tabular Q-Learning 1.

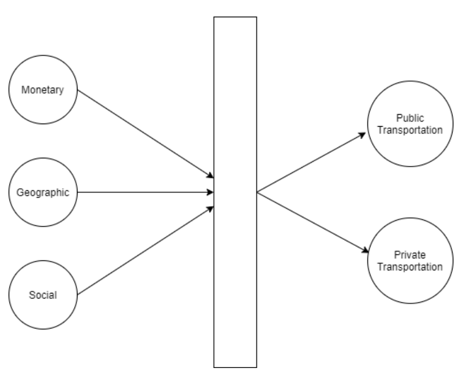


Fig. 1. High Level representation of the system

A. Inputs and Outputs Variables

- **Input Variables**
  - Number of private and public transports
  - Number of commuters
  - CO_2 emissions per transport
  - Transports speed limitations
  - Public transports average waiting time
  - Fuel prices
  - Toll fares
  - Ticket prices
  - Commuters' social awareness
  - Road's length
  - Road's condition
  - Policy to be applied [1]
- **Output Variables**
  - Average travel time
  - System's CO2 emissions
  - Commuters chosen transportation percentages
  - Average transportation costs [2]

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 to draw conclusions about the behavior of the population is based on some hypotheses that we want to be proven or disproved.

Only one parameter will be 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.

[1]Certain policies may not include all of the Input Variables specified above

[2]This value reflects the average cost for each commuter of the system that chooses different transportation

- If the values go up, it is specable that after a certain margin of acceptance, more than 25% of people prefer to switch to public transportation.

- **Social awareness**
  - The higher the awareness (values close to 1), the greater the use of public transport.
  - Conversely, the closer to 0, the lower the usage.
- **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 will be the target of evaluation throughout the simulation.

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

As the focus of the simulation will consider only two roads (one for public transport and one for private transport), the different analyzes will be based on 3 different scopes, that is, each policy stated below will be tested for 3 different road sizes (5 , 10 and 20km). In this way, by varying the length of the road, factors such as cost, time and emissions will also be affected, and in this way there will be the possibility to study in detail the weight of each parameter in decision making.

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

- **Variation in the price of bus tickets**
  - There will be 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 will be 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 will react 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 commuters' social awareness**
  - Variation associated with public transportation to test to what extent the commuters' social awareness affects their decision-making process. This scenario consists in having a value, varying from 0 to 1, to measure the impact of situations, like the marginality in some locals or extreme cases like the COVID-19 pandemic, that rocket the commuters' fear to travel in buses.
- **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 will be 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.
- **Toll fares**
  - Variation associated with private transportation, more specifically in toll fares' price. This variation intends to identify the maximum amount commuters are willing to spend on toll fares to avoid having to use buses.
- **Speed limitations**
  - Scenario to compare how speed limitations affect each transportation mode. It will be 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.
- **Variation in the road's condition**
  - Scenario to compare how the road's condition affects each transportation mode. In this case, it will be possible to identify and perceive how this aspect affects both the public and the private transportation and to what extent it is a key factor in the commuter's decision-making process, in other words, test if a commuter that usually uses its own car to travel will change to public transports if the road he uses is in bad condition or vice versa.

V. Formalization

A. Variables and respective domains

The system will be 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 commuters will have a characteristic variable:

- **Commuter's social awareness**: float value varying between 0 and 1.

The public transportation will also be 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 will also have specific variables such as:

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

Besides these variables, both transportation modes will be affected by:

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

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

- **Road's length**: integer value used to express a size, in kilometers (km).
- **Road's condition**: float value varying between 0 and 1.

Finally, there will be 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 (€)
- **Commuters chosen transportation percentages**: float value used to express a percentage.

B. Constraints

The work to be developed has some constraints regarding the environment in which the simulations will occur:

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

*2) **Origin and arrival points**:* The commuters will 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., will be based on the values currently applied in Portugal.

C. Objective Function

In this project two different objective functions are going to be 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 will be 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 are going to be 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 will be 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
- All commuters that are at the stop at the time the bus passes can enter (there is no maximum capacity)
- 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 will be as 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 will be varied during the execution of the scenarios.

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

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

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

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

$$\textit{No. Commuters} = 1000$$

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

$$\textit{Emissions Public Transp.} = 20g/km$$

$$\textit{Emissions Private Transp.} = 100g/km$$

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

$$\textit{Speed Public Transp.} = 11m/s$$

$$\textit{Speed Private Transp.} = 14m/s$$

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

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

*6) **Fuel prices**:* Value that will only influence private transportation.

$$\textit{Fuel price} = €1.40$$

*7) **Toll fares**:* Value that will only influence private transportation.

$$\textit{Toll far} = €1.00$$

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

$$\textit{Ticket price} = €2.00$$

*9) **Commuters' social awareness**:* Refers to the availability of agents to travel in public transport. Value that will follow a normal distribution and that will have values between 0 and 1.

$$\textit{Social awareness} = 0.5$$

*10) **Road's length**:* Value that will affect both transports.

$$\textit{Road length} = 10km$$

*11) **Road's condition**:* Value that will affect both transports. Value between 0 and 1, being 1 a road in excellent condition.

$$\textit{Public road condition} = 0.8$$

$$\textit{Private road condition} = 0.8$$

*12) **Policy to be applied**:* Value that dictates the scenario to be studied during a given simulation. It affects both transports.

$$\textit{Policy} = 1$$

B. Cognitive Model description

The simulation system Agents will have to make decisions regarding the type of transport to use to move from origin to destination. As such, it is 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** will be used based on the **Q-Learning** tabular method.

In order to make this possible, Agents will 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.

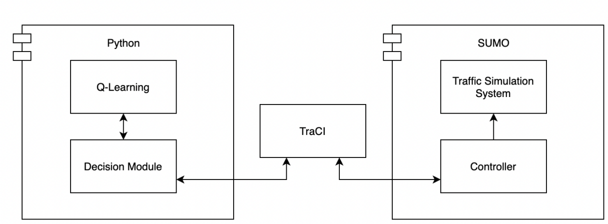
After each iteration, the Agent will update its value in the table, and will have it as a reference in the following iterations. Through Reinforcement Learning, the Agent will be able to understand over time what type of transport to use. The goal is for each agent to make the decision that meets their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

Since a model with a single starting point will be used, the Table will only have one **State**. As far as **Rewards** are concerned, their value will be 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.

VIII. Diagrams

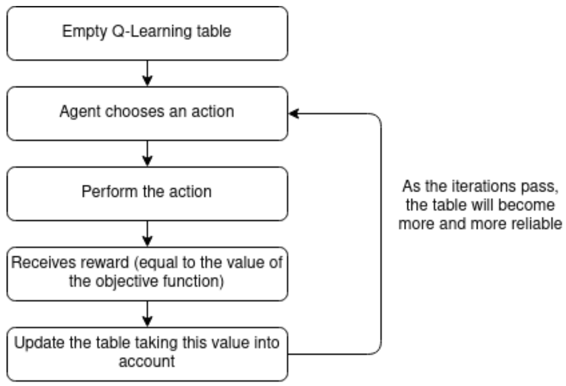
This section expands on the details of the project's architecture, from top to bottom.

A. 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



The decision process is based on a tabular **Q-Learning** which aims to replicate how human beings act. Each iteration will serve as feedback, thus allowing agents to improve and take better and better decisions.

C. Block diagram

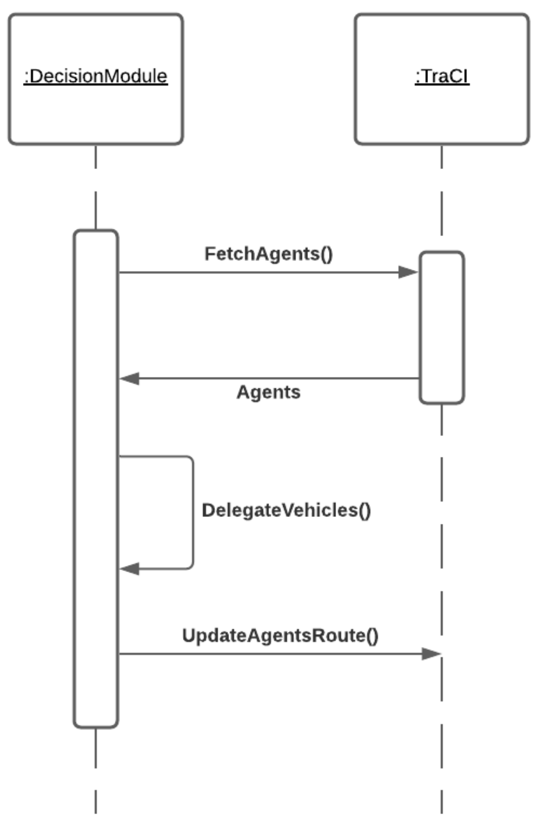


Fig. 2.

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 Q-Learning 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 will simulate a year[3], in order to allow it to stabilize. The results of the previous day will be the input to the **Q-Learning** engine.

A. Warm-ups

With the objective of replicating real-life scenarios, each simulation step will start with a considerable number of vehicles [4]. By doing this, there is an introduction of congestion in the system, which allows a more thorough simulation and high fidelity results.

References

[1] Z. Kokkinogenis, N. Monteiro, R. J. F. Rossetti, A. L. C. Bazzan and P. Campos, ”Policy and incentive designs evaluation: A social-oriented framework for Artificial Transportation Systems,” 17th International IEEE Conference on Intelligent Transportation Systems (ITSC), Qingdao, China, 2014, pp. 151-156, doi: 10.1109/ITSC.2014.6957682.

[2] TraCI - SUMO Documentation - https://sumo.dlr.de/docs/TraCI.html

[3] PyPI: The Python Package Index - https://pypi.org/

[3]365 days

[4]Number of needed vehicles to congest the system