Design of a Car Sharing System

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Abstract

The car modal share in Lisbon increased by 9.4% in a span of 10 years, from 2001 to 2011, and is a problem that must be addressed in order to have a sustainable transport system. This problem has consequences, namely parking shortage and underdevelopment of other modes of transport. After analysing which are the factors that influence a person in choosing a transport mode, a model of the system was created using Systems Modeling Language (SysML). Each transport provider was modelled as a public entity and as a system actor, along with the system's transport authority, the entity responsible for the parking and the customer. The constructed model has 6 key variables, 32 auxiliary variables and 5 counters, 7 actors, and 27 use cases used to describe the problem. The system model provides a framework to achieve a solution to the problem, consisting in having a city-wide network, a public transport provider for each of the modes of transport, unifying them physically, and through a unique ticketing system and with a unique information platform. The car sharing system was designed as a public transport operator, has the objective of serving as a replacement to the use of the private vehicle and as a gateway to the other modes for the citizen that only use the car.

Keywords: Systems Modeling Language, Shared mobility, Public transport, Sustainable mobility

1. The Problem

The transportation sector is a major consumer of energy and emitter of greenhouse gases. In 2014, of the total 15.17 Mtoe of final energy consumed in Portugal, the transportation sector consumed 36.3%, making it the activity sector with the biggest consumption of final energy, followed by the industry sector with 34%, domestic sector with 16.9% and the services sector with 12.8% [1]. During the same year, the Portuguese economy released 65 331.3 tonnes of CO_2eq [2]. The transport sector share was 36.7%, where road transport dominated by a relative share of 95.7% [3].

1.1. Modal share

Each citizen has an array of modes of transport available. These can be divided into motorized and soft modes (non-motorized). Motorized modes of transport are further divided into private and public transport. Private modes are cars and motorcycles, while public transport encompasses buses, light rail, subway, trains, and boats. Soft modes are the bicycle and walk. Figure 1 shows all the different modes and their division.

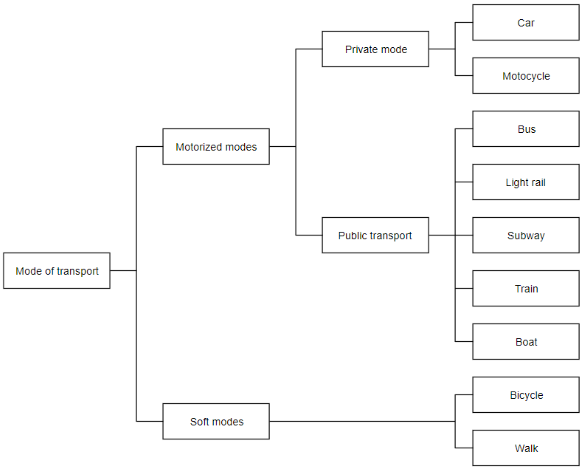

Figure 1: Modes of transport.

The concept of modal share is used to compare the utilization of each mode. It's given by the ratio between a mode's unit of measurement and the sum of the same unit for all transport modes. Modal share may be used as a gauge of a transport system sustainability [4]. High shares of public transport or soft modes indicates a more sustainable use of transport modes.

The modal share of commuting trips in Lisbon is shown in figure 2. Commuting trips are accountable for most of the emissions and traffic generation during the day. Therefore, their share is considered to be an acceptable indicator of the residents' transportation habits [5, 6].

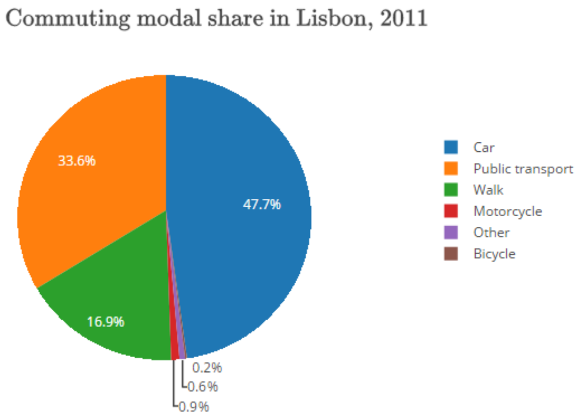

Figure 2: Modal share of commuting trips in the city of Lisbon, 2011 [7].

Comparing to 2001 to 2011, the car share increased from 38.3% to 47.7% to the detriment of public transport and walk share [7].

The increasing car modal share is the problem addressed in this work. The consequences regarding the transport system are the shortage of parking and underdevelopment of other modes. Thus other modes aren't accessible citywide, aren't sufficiently interconnected, either physically or monetarily, don't have enough capacity to handle the required flow of users and aren't reliable.

1.2. Modal choice

Comprehending the reasoning behind the user's decisions leads to the relevant system's characteristics. The adopted definition of modal choice is: "the decision process to choose between different transport alternatives, which is determined by a combination of individual socio-demographic factors and spatial characteristics, and influenced by social factors" adapted from [8, p. 331].

1.2.1 Socio-demographic factors

Socio-demographic factors frame the user's travel needs and social interactions.

1.2.2 Spatial characteristics

Spatial characteristics describe the physical environment in which the journey takes place and describe the conditions in which the journey is made.

1.2.3 Social factors

The social factors are the filter between the physical system and what the user considers to be suitable for their needs.

1.3. System environment

The problem affects Lisbon's transport system and it's necessary to describe its surroundings. The system is bound by the city's limit. The transport system of Lisbon, not only has to deal with the local population, but it also has to deal with the daily commuters coming from surrounding counties [?].

1.4. Actors

An entity that actively interacts with the system is considered an actor. It can not only be a physical person or system, but also a company. The system's boundary dictates what is considered an actor and what is considered part of the system itself.

The system has seven distinct actors as shown in figure 3. These are the system's costumer, CML, EMEL, Carris, Metro, BSP and CSP.

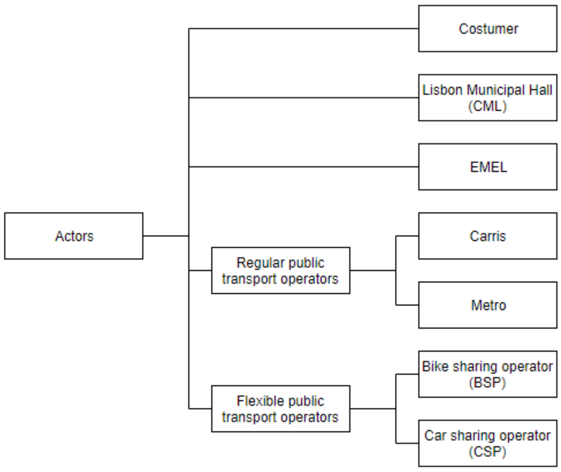

Figure 3: System's actors.

Actors interact with the system through use cases. These describe actions performed by an actor and dictate how the variables change. They can increase, decrease or converge the value of a given variable.

1.4.1 Customer

A customer is a person who uses the transport system. It's this actor who dictates the required system capacity. The providers have to follow the costumers daily travel patterns and provide an adequate service.

All of its use cases are instances of usage. Depending on the mode chosen for the journey, a different use case will be triggered. Since walking doesn't require a public transport service to exist, no use case is modelled after it.

1.4.2 CML

Lisbon Municipal Hall is the transport authority of Lisbon's transport system. It's responsible for the bike lane network, for handling the systems' information as a whole, for creating transport hubs and for integrating the means of access to different systems, i.e. it creates different public transport passes that integrates different operators.

1.4.3 EMEL

Despite EMEL being overseen by CML, it's treated as a separate entity. In order to manage the parking, EMEL can increase or decrease the parking prices as well as providing more parking spaces or cutting them back.

1.4.4 Carris

Carris provides the bus service. Its system covers most of Lisbon, covering approximately 99% of the city's area (this excludes the area covered by the airport and by the Monsanto forest park). The area is based on a 5 minutes walking distance from each bus station, assuming an average walking speed of 1.29 ms^{-1} [9]. Thus, this actor doesn't have the need to expand its transport network.

Carris can deploy more buses if they wish to increase the service or recall buses if they wish to decrease the service. It also handles information regarding the bus service.

1.4.5 Metro

The subway network is managed by the Metropolitano de Lisboa (Metro). The subway network is limited and covers approximately 57% of the city area considering a 10 minutes walking distance from the nearest subway station.

Metro can expand the subway network by creating subway stations. In order to manage the service capacity, it can deploy or recall trains. Metro also handles its information.

1.4.6 BSP

There are two bike sharing operators in Lisbon, Gira - Bicicletas de Lisboa [10] and oBike [11]. Gira is a one-way bike sharing system, where the customer can rent a bicycle and then end the journey in a dedicated station. The bike sharing provider (BSP) is modelled as a public service operator, implying that the BSP may have to fulfil public service obligations, that will be compensated by the transport authority.

Gira is used as the base for the model bike sharing provider and as such covers approximately 16% of the city's area.

The BSP can expand the network by creating bike sharing stations and manage their occupancy rate by relocating bicycles. BSP handles the information of the system.

1.4.7 CSP

There are currently four distinct car sharing companies operating inside Lisbon, namely Hertz 24/7™Car Sharing [12], Citydrive [13], DriveNow [14] and emov [15]. All of these companies utilize a free-floating car sharing system. The customer can pick up and leave the car anywhere within the operational area. The car sharing provider is modelled as a public service operator.

The operational area of the car sharing system is the area in which the customer can start or end a trip. The operational area for the car sharing provider is based upon DriveNow's covering 68% of the city area.

The car sharing operator commands a free-floating car sharing system. It can expand the operational area in order to change the service's coverage. The car fleet is managed by deploying more cars and by relocating cars. The relocation is used in order to grant that there are cars where there are customers. CSP handles the system's information. As an example of a use case diagram, the CSP diagram is shown in figure 4.

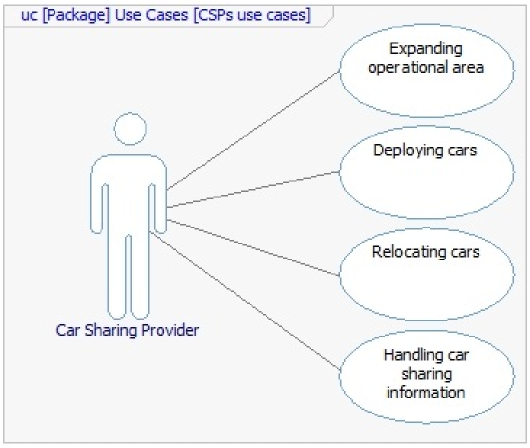

Figure 4: CSP's use cases.

1.5. Variables

Given the problem's consequences and the factors that influence modal choice, there are six variables used to describe it. These are key variables and are the main descriptors of the problem, they quantify it and create its boundaries. However, it's necessary to resort to auxiliary variables in order to fully describe the problem.

A system's variable is described by its name, how it's measured or observed, appropriated units of measurement or quantification scales, the present and desired behaviour over time (BOT), the way the variable is calculated and how it's affected by the interactions with the system's actors. For auxiliary variables the desired BOT may not necessary [16].

1.5.1 K_1 – Parking Easiness

Parking easiness is defined as the probability of a car driver finding an empty public parking sport.It has a quantification scale between 0 and 1, where 0 means that there's no parking spot available to the customer and 1 means that the customer finds a vacant parking sport immediately whenever desired. The current BOT is to decrease and the desired BOT is to remain stable at a value of 0.2.

This variable is computed from three auxiliary variables: A$_{01}$ - "Average Parking Price", A$_{02}$ - "Quantity of Parking Spaces" and A$_{03}$ - "Quantity of Cars". The relationship between these variables is given by equation 1.

$$K_1 = \frac{A_{01}}{(A_{01}+1)\left(e^{\frac{-A_{02}}{a}+b}+1\right)\left(e^{\frac{A_{03}}{c}+d}+1\right)} \tag{1}$$

Where a, b, c and d are parameters to adjust how the function behaves. This relationship is based on the assumptions that the parking easiness varies with the inverse of the average ticketing price, and that the relationship between the quantity of parking spaces and quantity of cars with K$_1$ is given by a sigmoid function.

1.5.2 K$_2$ – Bike Lanes Density

It's defined as the usable bike lanes' length divided by the useful city's area (road area). This variable is measured in length divided by area and has units of km^{-1}. The current BOT is to increase the variable's value, and the desired BOT is to remain stable at or above the road density. Road density is considered to be a constant in the system.

As shown in equation 2, this variable is calculated using two auxiliary variables: A$_{04}$ - "Total Bike Lanes Length" and A$_{05}$ - "Share of Usable Bike Lanes". The road area is considered to be constant.

$$K_2 = \frac{A_{04}A_{05}}{r_a} \tag{2}$$

1.5.3 K$_3$ – Information Utility

Information utility is defined as the average level of information quantity, quality, and placement regarding the public transport system. It has a quantification scale between 0 and 4, where 0 means that there's no information available to the customer and 4 means that all the information that the customer may need is available, that it's placed in an easy to access location and has the highest level of detail without being cumbersome. The desired BOT is to remain stable at a level higher than 3.25.

This variable is computed by the sum of four auxiliary variables multiplied by another, as shown in equation 3. Variables A$_{06}$ to A$_{09}$ deals with the information of a specific system while A$_{10}$ deals with information regarding how the systems interact as one.

$$K_3 = (A_{06}+A_{07}+A_{08}+A_{09})\,A_{10} \tag{3}$$

1.5.4 K$_4$ – Systems Interconnectivity

Key variable four is defined as the number of transport hubs multiplied by the normalized number of services that use the same ticketing systems. It's dimensionless and has a domain of $\mathbb{R}^+$, where 0 means that no subsystem have overlapping access points or every provider has their own ticketing system.

As shown in equation 4, K$_4$ requires two auxiliary variables: A$_{11}$ - "Quantity of Hubs" and A$_{12}$ - "Quantity of Ticketing Systems". Since there are 4 distinct systems, if A$_{12}$ is subtracted from 5 and then divided by 4, the result is the normalized number of services that use the same ticketing system.

$$K_4 = A_{11}\frac{5-A_{12}}{4} \tag{4}$$

1.5.5 K$_5$ – System Coverage

System coverage is defined as the maximum city's area share within 5 minutes walking distance from the nearest bike sharing and bus access points, within 10 minutes walking distance from the nearest subway access point and inside the car sharing service operational area. It has a quantification scale between 0 and 1, where 0 means that there's no area within the city that's in 5 minutes walk from all the different system's access points and 1 means that the whole city is covered by all the systems.

As seen in equation 5, K$_5$ is obtained from the intersection of the coverage zones of the different systems. This ensures an accurate representation of the zones where all the services overlap.

$$K_5(A_{13}, A_{14}, A_{15}) = b_{sc} \cap A_{13} \cap A_{14} \cap A_{15} \tag{5}$$

1.5.6 K$_6$ – Systems Capacity and Availability

Services capacity and availability is defined as the system's capacity to manage the required workload at any given time. It has a domain of $\mathbb{R}^+$, where 0 means that no system is working at the moment and can't transport any costumer, 1 means that the system has the exact capacity to transport all the customers at the moment and above 1 means that the system has higher capacity than that required.

As shown in equation 6, this variable is calculated by adding all the different services capacity and availability and dividing by the required system capacity.

$$K_6 = \frac{A_{16}+A_{17}+A_{18}+A_{19}}{A_{20}} \tag{6}$$

A$_{16}$ – Bus system capacity

The bus system capacity is defined as the number of persons that the bus system is able to transport in an hour. It's measured in passenger/hour, has a domain of $\mathbb{R}^+$, and is calculated using eq. 7. The quantity of bus lines (b$_l$) and the average number of passengers per bus (b_c) are considered to be constant. Thus, in order to change its capacity, Carris must change the bus passage frequency (A_{21}).

$$A_{16} = A_{21} b_c b_l \tag{7}$$

A_{17} – Subway system capacity

Defined as the number of persons that the subway system is able to transport in an hour. It's measured in passenger/hour, has a domain of $\mathbb{R}^+$, and is calculated using eq. 8. To alter its capacity, Metro can change A_{22} – "Average Train Passage Frequency" or A_{23} – "Quantity of Subway Lines". The Metro has the same mechanisms of service maintenance as Carris and it can be expanded with the creation of new subway lines.

$$A_{17} = A_{22} A_{23} t_c \tag{8}$$

A_{18} – Bike sharing system availability

The bike sharing system has a limited availability since it's not usable if there are no available bicycles. It's defined as the number of persons that the bike sharing system is able to transport in an hour. It's measured in passenger/hour, has a domain of $\mathbb{R}^+$, and is given by equation 9. This definition requires three auxiliary variables: A_{24} – "True Capacity Factor", A_{25} – "Bicycle Fleet Size" and A_{26} – "Average Bicycle Trip Time".

$$A_{18} = \frac{A_{24} A_{25}}{A_{26}} \tag{9}$$

A_{24} is defined as the ratio between effective stations and the total number of stations. Effective stations are neither full nor empty. When it's 0, all stations are either completely empty or full and when it's 1, no stations are either completely empty or full. It's dimensionless and has a domain of [0,1]. This variable requires the definition of three additional auxiliary variables: A_{27} – "Quantity of Bike Sharing Stations", A_{28} – "Quantity of Full Bike Sharing Stations" and A_{29} – "Quantity of Empty Bike Sharing Stations". Their relationship is given by equation 10.

$$A_{24} = 1 - \frac{A_{28} + A_{29}}{A_{27}} \tag{10}$$

A_{19} – Car sharing system availability

Similarly to the bike sharing system, the car sharing system has an upper limit in its availability. It's defined as the number of persons that the car sharing system is able to transport in an hour. It's measured in passenger/hour, has a domain of $\mathbb{R}^+$, and is given by equation 11. This equation has two constants: c_c – "Average car capacity" and param_{CDG} – "Car density gradient reference value"; and it has three auxiliary variables: A_{30} – "Car Fleet Size", A_{31} – "Average Car Trip Time" and A_{32} – "Car Density Gradient". The system's availability increases linearly with the amount of cars in its fleet and varies inversely with the average time that the customer expends using the system.

$$A_{19} = \frac{c_c A_{30}}{A_{31}} \text{MIN}\left(1, \frac{param_{CDG}}{A_{32}}\right) \tag{11}$$

2. System Interactions and Behaviour

Once all the problem's variables, actors and use cases are defined, it's necessary to lay out how these interact with each other and how the system behaves. Table 1 shows all the actors, use cases and which variables are affected when they are executed.

Sequence diagrams are used in order to represent qualitative interactions between the different actors and variables through the execution of use cases. An actor uses the value of one or more variables and then trigger a use case. The value being used by the actor is represented by a data flow arrow and is labelled as "value".

To trigger an use case, the actor sends a create arrow labelled "Create()". The use case can have one or more effects. To indicate that the use case execution changed a variable value, it's used an event arrow. It can be labelled as "increase()", "decrease()" or "converge()", depending on how the variable changes with the use case execution.

Lastly, some variables can change their value without a use case execution. In this case, the alteration is displayed on the diagram with an action block on the respective variable timeline.

An example of a sequence diagram is shown in figure 5. This diagram shows the interactions of the CSP in order to relocate vehicles.

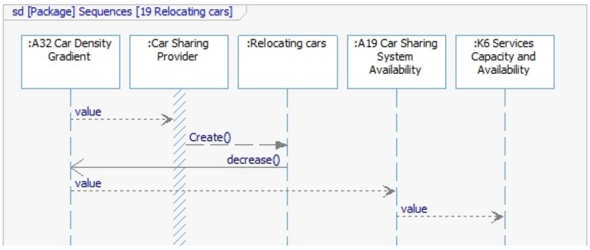

Figure 5: Sequence diagram 19 – Relocating cars

3. Constraints and Analysis

After the behaviour of the system has been laid out with sequence diagrams, it can be modelled with parametric diagrams. This type of diagram is used to explore the constraints of the system, when and/or how extensively the use cases are triggered.

Each actor is governed by a set of equations. These are symbolic and needed in order to model a

Table 1: Actors, use cases and affected variables

Triggering Actor	Use Case	Affected Variable
EMEL	Increasing parking prices	A_{01} Average Parking Price
	Decreasing parking prices	A_{01} Average Parking Price
	Creating parking spaces	A_{02} Quantity of Parking spaces
	Decreasing parking spaces	A_{02} Quantity of Parking spaces
Customer	Using private vehicle	A_{03} Quantity of Cars
	Walking	A_{20} Required System Capacity
	Using regular public transport	A_{20} Required System Capacity
	Using bike sharing system	A_{20} Required System Capacity
		A_{26} Average Bicycle Trip Time
		A_{28} Quantity of Full Bike Sharing Stations
		A_{29} Quantity of Empty Bike Sharing Stations
	Using car sharing system	A_{20} Required System Capacity
		A_{31} Average Car Trip Time
		A_{32} Car Density Gradient
CML	Building bike lanes	A_{04} Total bike lanes extension
	Maintaining bike lanes	A_{05} Share of usable bike lanes
	Handling systems information	A_{10} Systems information
	Creating transport hubs	A_{11} Quantity of hubs
	Integrating means of access	A_{12} Quantity of Ticketing Systems
Carris	Handling bus information	A_{06} Bus System Information
	Deploying buses	A_{21} Average Bus Passage Frequency
	Recalling buses	A_{21} Average Bus Passage Frequency
Metro	Handling subway information	A_{07} Subway System Information
	Creating subway stations	A_{13} Subway System Coverage
		A_{23} Quantity of Subway Lines
	Deploying trains	A_{22} Average Trains Passage Frequency
	Recalling trains	A_{22} Average Trains Passage Frequency
BSP	Handling bike sharing information	A_{08} Bike Sharing System Information
	Create bike sharing station	A_{14} Bike Sharing System Coverage
		A_{25} Bicycle Fleet Size
		A_{27} Quantity of Bike Sharing Stations
	Relocating bicycles	A_{28} Quantity of Full Bike Sharing Stations
		A_{29} Quantity of Empty Bike Sharing Stations
CSP	Deploying cars	A_{03} Quantity of Cars
		A_{30} Car Fleet Size
	Handling car sharing information	A_{09} Car Sharing System Information
	Expanding operational area	A_{15} Car Sharing System Coverage
	Relocating cars	A_{32} Car Density Gradient

given problem since no person is actually ruled by a set of immutable equations. The same is applicable to use cases.

The constraints are modelled using constraint blocks. These blocks have ports, for input and output of information, and also constraints. These are the equations that determine behaviour.

3.1. Actor parametrics

All equations that govern the behaviour of the actors are displayed in table 2. These equations are conditions that when met trigger the respective use case. The actors use values from parts of the system, such as the value of key variables or values from their respective subsystem. There are also some parameters in addition to the variables: $\text{Param}_{\mathbf{Dist}}$ trip distance. $\text{Param}_{\mathbf{BSA}}$ bike sharing service attractiveness. $\text{Param}_{\mathbf{CSA}}$ car sharing service attractiveness. $\text{Param}_{\mathbf{PVA}}$ private vehicle attractiveness. $\text{Param}_{\mathbf{RPTA}}$ regular public transport attractiveness. $\text{Param}_{\mathbf{A}}$ set of all modes attractiveness. $\text{Param}_{\mathbf{CA}}$ car availability. $\text{Param}_{\mathbf{PTP}}$ public transport pass. $\text{Param}_{\mathbf{Info}}$ relates to the amount of information regarded as necessary for the customer to choose a mode. $\text{Param}_{\mathbf{RD}}$ road density. $\text{Param}_{\mathbf{BS}}$ share of the required capacity that the bus service should handle. $\text{Param}_{\mathbf{SS}}$ share of the required capacity that the subway service should handle. $\text{Param}_{\mathbf{NL}}$ new line. $\text{Param}_{\mathbf{CDG}}$ car density gradient reference value.

3.2. Use case parametrics

Once a use case is triggered, it is its parametric diagram that shows what is the outcome. Most of the outputs in this model are equal to the input that triggered the use case and is represented by "Cre-

Table 2: Actors parametric equations.

Triggering Actor	Use Case	Equation
EMEL	Increasing parking prices	$if(0.3 \geq K_1 > 0.2)$ then $DIPP$ else 0
	Decreasing parking prices	$if(0.2 > K_1 \geq 0.05)$ then $DDPP$ else 0
	Creating parking spaces	$if(0.05 > K_1)$ then $DCPS$ else 0
	Decreasing parking spaces	$if(K_1 > 0.3)$ then $DDPS$ else 0
Customer	Using private vehicle	$if[par_D > 0.774 \wedge par_{CA} = 1 \wedge$ $par_{PVA} = \text{MAX}(par_A)]$ then 1 else 0
	Using regular public transport	$if[par_D > 0.774 \wedge par_{RTP} = 1 \wedge K_3 > par_I \wedge$ $par_{PVA} = \text{MAX}(par_A)]$ then 1 else 0
	Using bike sharing system	$if[0.774 < par_D < 6.25 \wedge K_3 > par_I \wedge$ $par_{BSA} = \text{MAX}(par_A)]$ then 1 else 0
	Using car sharing system	$if[par_D > 0.774 \wedge K_3 > par_I \wedge 0$
		$par_{CSA} = \text{MAX}(par_A)]$ then 1 else 0
CML	Building bike lanes	$if(K_2 < par_{RD})$ then DBL else 0
	Maintaining bike lanes	$if(A_{05} < 1)$ then 1 else 0
	Handling systems information	$if(A_{10} < 0.9)$ then 1 else 0
	Creating transport hubs	$if(A_{11} < 10)$ then DTH else 0
	Integrating means of access	$if(A_{12} \neq 1)$ then DTS else 0
Carris	Handling bus information	$if(A_{06} < 0.9)$ then 1 else 0
	Deploying buses	$if(A_{16} < par_{BS}A_{20})$ then $DBus$ else 0
	Recalling buses	$if(A_{16} > par_{BS}A_{20})$ then $RBus$ else 0
Metro	Handling subway information	$if(A_{07} < 0.9)$ then 1 else 0
	Creating subway stations	$if(A_{13} < 67.39)$ then DSS else 0 $if(par_{NL} = 1)$ then DSL else 0
	Deploying trains	$if(A_{17} < par_{SS}A_{20})$ then $DTrains$ else 0
	Recalling trains	$if(A_{17} > par_{SS}A_{20})$ then $RTrains$ else 0
BSP	Handling bike sharing information	$if(A_{08} < 0.9)$ then 1 else 0
	Create bike sharing station	$if(A_{14} < 67.39)$ then $DBSS$ else 0
	Relocating bicycles	$if(A_{24} \neq 1)$ then DRB else 0
CSP	Deploying cars	$if(K_6 < 1 \wedge A_{30} = C_5)$ then DC else 0
	Handling car sharing information	$if(A_{09} < 0.9)$ then 1 else 0
	Expanding operational area	$if(A_{15} < 67.39)$ then DOA else 0
	Relocating cars	$if(A_{32} \geq par_{CDG})$ then DRC else 0

ate", as displayed in table 3. In the cases where the input has different units than the output, there's a condition to be met. When the condition is fulfilled, the output is different from 0.

3.3. Variables parametrics

After a use case is finished, its outcome will change the value of one or more variables. This is represented by a parametric diagram. Every variable has one parametric diagram and one equation to determine its new value. Table 4 displays the equations used for each dynamic variable and counter. The equations for the computed variables were given in section 1. The dynamic variables are calculated by adding or subtracting one or more outputs that come from the use cases. However, some variables are averages and require a counter. Their equations differ from the others.

3.3.1 Average frequency

The average frequency is calculated assuming that the quantity of circulating vehicles and the variation of vehicles is the same for all lines. Equation 12 is used for the parametric diagrams of A$_{21}$ and A$_{22}$.

$$\bar{f}' = \bar{f}\left(1 + \frac{dm}{m}\right) \tag{12}$$

where $\bar{f}'$ is the new average frequency, $\bar{f}$ is the previous average frequency, m is the number of circulating vehicles and dm is the variation in the number of vehicles.

3.3.2 Average trip time

The average trip time follows the structure of equation 13 and is used for A$_{26}$ and A$_{31}$.

$$\bar{x}' = \bar{x} + \frac{\sum_{i=n}^{n+d} x_i - d\bar{x}}{n+d} \tag{13}$$

where $\bar{x}'$ is the new average, $\bar{x}$ is the previous average, n is the number of entries used for the previous average, d is the number of new entries and x_i is the new entry i.

3.4. Analysis and proposed solution

3.4.1 Services accessibility

Currently, only the subway and the bus service are considered public transport, and as such, approximately, only 57% of the total city area is covered

Table 3: Use cases parametric models

Use Case	Output	Equation
Increasing parking prices	iPP	Create
Decreasing parking prices	dPP	Create
Creating parking spaces	cPS	Create
Decreasing parking spaces	dPS	Create
Using private vehicle	dCU	if (UsePV=1) then 1 else 0
Using regular public transport	uRPT	if (UseRPT=1) then 1 else 0
Using bike sharing system	uBS	if (UseBS=1) then 1 else 0
	uT_{BS}	if (UseBS=1) then DTBS else 0
	uF	if (UseBS=1) then DFBSS else 0
	uE	if (UseBS=1) then DEBSS else 0
	uB	if (UseBS=1) then 1 else 0
Using car sharing system	uCS	if (UseCS=1) then 1 else 0
	uT_{CS}	if (UseBS=1) then DTCS else 0
	uGrad	if (UseBS=1) then UGrad else 0
	uC	if (UseCS=1) then 1 else 0
Building bike lanes	dL	Create
Maintaining bike lanes	dL_m	if (MaintainBL≠0) then DMBL else 0
Handling systems information	dISs	if (HandSsI=1) the DISs else 0
Creating transport hubs	dTH	Create
Integrating means of access	dTS	Create
Handling bus information	dIB	if (HandBI=1) the DIB else 0
Deploying buses	dB	Create
Recalling buses	rB	Create
Handling subway information	dIS	if (HandSI=1) the DIS else 0
Creating subway stations	dSC	CreateSS
	dN_{sl}	NewSL
Deploying trains	dT	Create
Recalling trains	rT	Create
Handling bike sharing information	dIBS	if (HandBSI=1) the DIBS else 0
Create bike sharing station	dBSC	if (CreateBSS≠0) then DBSC else 0
	cB	if (CreateBSS≠0) then CB else 0
	dBSS	Create
Relocating bicycles	dF	if (RelocBi≠0) then DF else 0
	dE	if (RelocBi≠0) then DE else 0
Deploying cars	dC	Create
Handling car sharing information	dICS	if (HandCSI=1) the DICS else 0
Expanding operational area	dA	Create
Relocating cars	rGrad	Create

with all public transport services. The model only has options to increase the coverage of the different systems because it's not fruitful to also model use cases that will decrease the coverage since it's currently insufficient.

Apart from physical integration, each system has its own ticketing system. The regular transports have VIVA [17], the bike sharing service and each car sharing provider have different means of access. With segregated ticketing systems, it's difficult for the customer to use different services while making a journey. System unification also leads towards system robustness, i.e. even if one subsystem has a perturbation or is inoperable, the system as a whole is able to adjust and handle the required service capacity.

Expanding each service coverage and unifying their ticketing system will improve their overall attractiveness to the customer. Once a public transport mode has a higher attractiveness than the private vehicle, the former will be used instead of the latter, thus reducing the problem in question.

3.5. Information and reliability

The information was modelled to represent another threshold to use a service. If the information is deemed insufficient by the customer, they will not choose that mode.

Nowadays, there's one multimodal information platform, TRANSPORLIS [18], that has information regarding the regular transport services within the city. With one information system that integrates all the different modes, the customer would be able to choose the most convenient to their needs.

Table 4: Dynamic variables and counters equations.

Variable	Equation
A_{01} Average Parking Price	$A_{01}^{new} = A_{01}^{old} + iPP - dPP$
A_{02} Quantity of Parking spaces	$A_{02}^{new} = A_{02}^{old} + cPS - dPS$
A_{03} Quantity of Cars	$A_{03}^{new} = A_{03}^{old} + dC + dCU$
A_{04} Total bike lanes extension	$A_{04}^{new} = A_{04}^{old} + dL$
A_{05} Share of usable bike lanes	$A_{05}^{new} = A_{05}^{old} + \frac{dL_m}{A_{04}}$
A_{06} Bus System Information	$A_{06}^{new} = A_{06}^{old} + dIB$
A_{07} Subway System Information	$A_{07}^{new} = A_{07}^{old} + dIS$
A_{08} Bike Sharing System Information	$A_{08}^{new} = A_{08}^{old} + dIBS$
A_{09} Car Sharing System Information	$A_{09}^{new} = A_{09}^{old} + dICS$
A_{10} Systems information	$A_{10}^{new} = A_{10}^{old} + dISs$
A_{11} Quantity of hubs	$A_{11}^{new} = A_{11}^{old} + dTH$
A_{12} Quantity of Ticketing Systems	$A_{12}^{new} = A_{12}^{old} - dTS$
A_{13} Subway System Coverage	$A_{13}^{new} = A_{13}^{old} + dSC$
A_{14} Bike Sharing System Coverage	$A_{14}^{new} = A_{14}^{old} + dBSC$
A_{15} Car Sharing System Coverage	$A_{15}^{new} = A_{15}^{old} + dA$
A_{20} Required System Capacity	$A_{20}^{new} = A_{20}^{old} + uBS + uCS + uRPT$
A_{21} Average Bus Passage Frequency	$A_{21}^{new} = A_{21}^{old}\left(1 + \dfrac{dB - rB}{C_1}\right)$
C_1 Quantity of Circulating Buses	$C_1^{new} = C_1^{old} + dBD - rB$
A_{22} Average Trains Passage Frequency	$A_{22}^{new} = A_{22}^{old}\left(1 + \dfrac{dT - rT}{C_2}\right)$
C_2 Quantity of Circulating Trains	$C_2^{new} = C_2^{old} + dT - rT$
A_{23} Quantity of Subway Lines	$A_{23}^{new} = A_{23}^{old} + dN_{sl}$
A_{25} Bicycle Fleet Size	$A_{25}^{new} = A_{25}^{old} + dB$
A_{26} Average Bicycle Trip Time	$A_{26}^{new} = if(uB = 1) \text{ then } A_{26}^{old} + \dfrac{uT_{BS} - A_{26}^{old}}{C_3 + 1} \text{ else } A_{26}^{old}$
C_3 Bike Sharing Trips Counter	$C_3^{new} = if(uB = 1) \text{ then } C_3^{old} + 1 \text{ else } C_3^{old}$
A_{27} Quantity of Bike Sharing Stations	$A_{27}^{new} = A_{27}^{old} + dBSS$
A_{28} Quantity of Full Bike Sharing Stations	$A_{28}^{new} = A_{28}^{old} - dF + uF$
A_{29} Quantity of Empty Bike Sharing Stations	$A_{29}^{new} = A_{29}^{old} - dE + uE$
A_{30} Car Fleet Size	$A_{30}^{new} = A_{30}^{old} + dC$
A_{31} Average Car Trip Time	$A_{31}^{new} = if(uC = 1) \text{ then } A_{31}^{old} + \dfrac{uT_{CS} - A_{31}^{old}}{C_4 + 1} \text{ else } A_{31}^{old}$
C_4 Car Sharing Trip Counter	$C_4^{new} = if(uC = 1) \text{ then } C_4^{old} + 1 \text{ else } C_4^{old}$
A_{32} Car Density Gradient	$A_{32}^{new} = A_{32}^{old} + rGrad + uGrad$
C_5 Quantity of Busy Cars	$C_5^{new} = C_5^{old} + uC$

3.6. Car sharing role

The intended role of the car sharing service is to replace the private vehicle use and at the same time serve as a gateway to the other public transport systems. The integration with other modes will allow the customer to become aware of the other options and may be able to use them. Treating the car sharing system as a public transport is necessary so that public transport obligations may be imposed.

4. Conclusions

The identified problem was the increasing car modal share for commute trips in the city of Lisbon. It entails two major consequences, a parking system overloading and a underdevelopment of other modes of transport. The underdevelopment can be broken down in parts regarding the public transport system coverage, interconnectivity and capacity.

To characterize the problem a model was constructed using SysML. The model is restricted to the city of Lisbon and its internal transport providers. After analysing the different factors that influence a citizen to choose a transport mode a simple was constructed with 6 key variables, 32 auxiliary variables and 5 counters, 7 actors, and 27 use cases. Most of the system's variables deal with average values.

The system model provides a framework to achieve a solution to the problem. This solution consists in having a public transport provider for each of the modes of transport, unifying them physically, and through a unique ticketing system and with a unique information platform. A car sharing system that is treated as a public transport provider would serve as a replacement to the use of the private vehicle and as a gateway to the other modes for the citizen that use the car as the only mode of transport.

4.1. Achievements

A simple model using Systems Modeling Language of the public transport system of the city of Lisbon was achieved in this work. This model characterizes the behaviour of the system showing how the actors interact with parts of the system. To analyse the constraints under which the system operates, it was created one parametric diagram for each actor, use case and variable.

4.2. Future works

Some future work would rely on adding more detail and depth to the model by cooperating with the different service providers.

Adding the different inter-municipal transport services and how the systems interact geographically would also be a good extension of the model. With its current format, the customers' origins are considered to start and end the journey inside Lisbon.

Finally, the car sharing system coverage is considered to be equal to its operational area. A dynamic coverage that takes into account the position of the each parked vehicle could be a more precise way of depicting the system's coverage.

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