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Site selection for electric cars of a car-sharing service

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Abstract

This study is carried out in the framework of SUCCESS (Smaller Urban Communities in CIVITAS for Environmentally Sustainable Solutions), an European project funded by the European Commission under the CIVITAS program. These demonstration projects provide a means of testing out a wide range of projects in a number of cities and the results of the evaluation will assist in showing which were successful, in what way and how that was achieved. One of these projects is the car-sharing implementation. Car-sharing is defined as a self service which allows to each subscriber for reaching a vehicle, for the duration and the way of his choice. In the current state, where the impacts of the pollution and the congestion of cities are increasingly acute, the car-sharing service can be an attractive complement for other means of transportation. For it, this type of service must ensure a high level of temporal and spatial availability. For the managers of a car-sharing service it means an efficient management of the existing system and for the local authorities it means the study of the opportunities of its extension. This work proposes to the decision makers an approach of aid to the extension of the service based on the modeling of the preferences of the potential users.

Keywords: Public transport, modeling, electric vehicle

1 Introduction

Car-sharing is defined as a system which allows to each subscriber for reaching a vehicle, for the duration and the way of his choice. But to provide good interoperability between public transport and car sharing vehicles, it is essential to place the stations in adequate places. The main reason is that the car-sharing services are most successful there where is sufficient economic and social activity and when that activity has a strong relationship to public transport.

Programs in some metropolitan cities such as Montreal, Boston, Seattle and San Francisco have grown rapidly, while others have stagnated

or have been forced to close through lack of usage [1]. Generally, studies and surveys confirmed that the land use, the population density and availability of public transport are key considerations to implement a car-sharing system. Local authorities of the small cities are generally reticent for implementing it because of the difficulty to calibrate the car-sharing service (location, number of cars) and to ensure the extension of the system.

Few works focuses on this last problem [2]. Multiple criteria evaluation (MCE) and optimization approaches are two major site selection approaches. During site selection procedure, MCE evaluates all locations on all attributes at the same level. Arentze [2] affirms

that Discrete MDCM (Multi Criteria Decision Making) methods help decision makers to judge the suitability of specific sites but they do not specify a search procedure for identifying the best sites from a given choice set.

Optimization approaches are mostly involved in hierarchical site selection procedure and in this kind of procedure all locations are evaluated as groups, according to different levels of criteria group [3].

Criteria such as the demographic level, the number of attractiveness points have been originally tested in past work by using the AHP method [4], [5]. We consider that several locations are pre-selected.

Now the problem of the local authorities is a classification problem in order to choose locations and to calibrate the stations in agreement with the number of the potential users. A solution could be to understand and to exploit the customer's preferences, even in a fuzzy manner, in order to anticipate the customers' needs. Our work is focused in the development of a methodology to aid decision makers for classifying locations for the car-sharing stations. This paper is organized as follows: section 2 presents the framework of this work. The interest

of up-scaling principle is presented in section 3. Section 4 proposes a method to collect data, to model the preferences of potential subscribers living or working in the selected area. The final section outlines the conclusions and the perspectives of our works.

2 Car-sharing in medium sized cities

2.1 SUCCESS project

This study is carried out in the framework of SUCCESS (Smaller Urban Communities in CIVITAS for Environmentally Sustainable Solutions, July 2005–December 2008) an European project funded by the European Commission under the CIVITAS program [6]. There are three cities (Ploiesti-Romania, Preston-UK, La Rochelle-France) where particular actions must be implemented, tested and evaluated. There are 56 actions such as the introduction of the GPL buses, the implantation of a park&ride service, the car-sharing or bike-sharing, the information systems, access controlled areas, etc.

The actions to carry out are distributed in the Work Packages (WP) (see Fig.1).

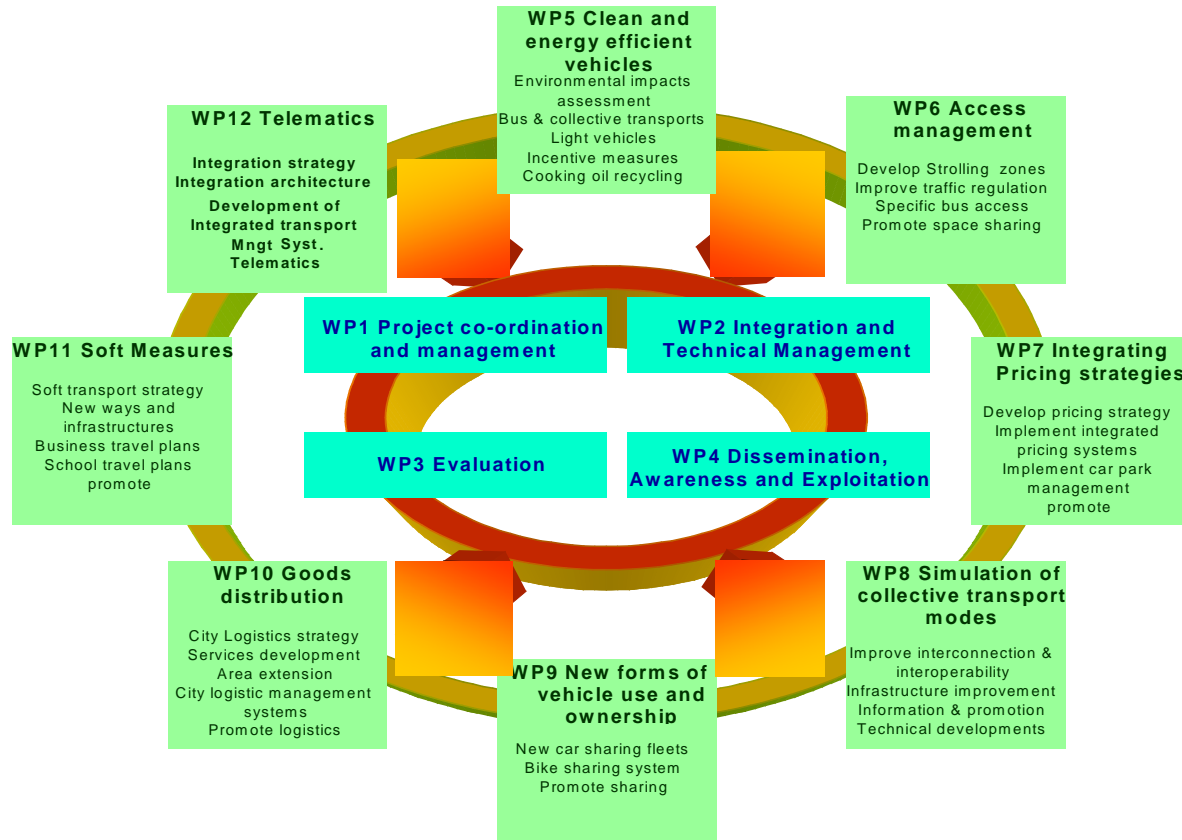


Figure1: Work packages of SUCCESS project [7]

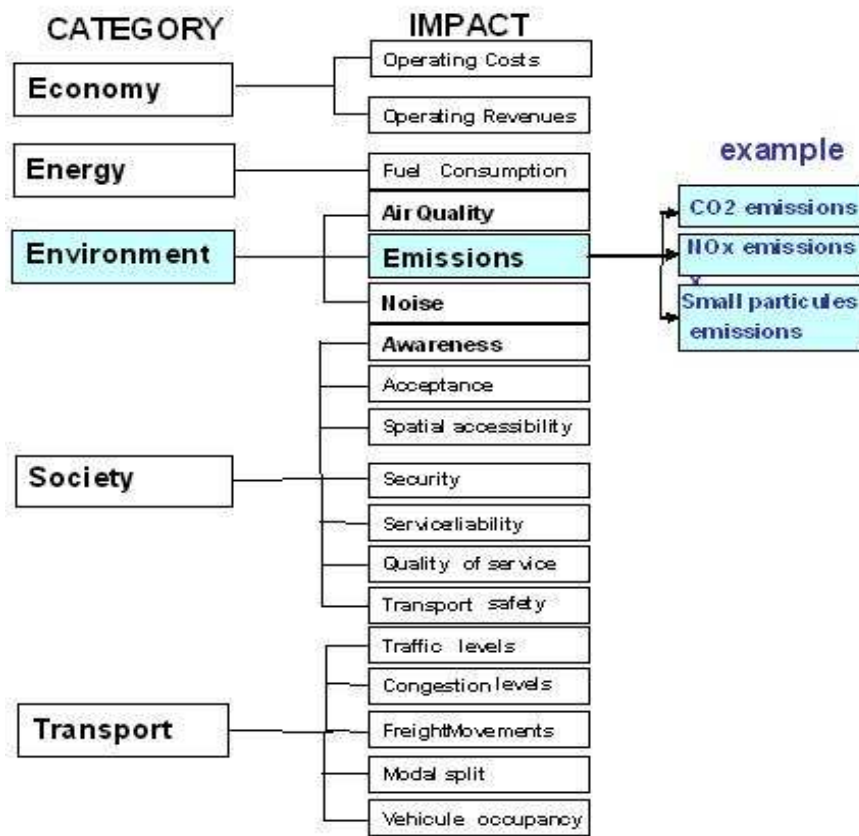


Figure2: List of impacts of a transportation project

For each one, an initial evaluation (before) and an ex-post evaluation (after) must be done (WP3) in order to estimate the impacts of these actions. Our work is done in the framework of the WP3 (Evaluation of Impacts of projects included in WP5-WP12).

The principal targets of actions are [7], [8], [9]:

1) Transport systems must be environmentally sustainable, not only at the point of use, but throughout the fuel and equipment production lifecycle. Fuel consumption must be appraised in terms of natural resources and security of supply.

2) To optimize urban transport in medium sized cities in an integrated manner. This will require a global approach to the design of the transport system in order to establish a coordinated mapping of resources, performance and user satisfaction.

3) To demonstrate that clean urban transport is efficient for city activities on a medium term horizon. Clean urban transport must be technically reliable and economically satisfactory, which means that in order not to increase city transport budgets, industrial and commercial performance must benefit from this implementation.

The impacts are generally distributed in 5 categories: economy (costs and benefices), energy (consumption), environment (air quality and noise), society (accessibility, safety), transport (service quality, transport system).

Each impact is characterized by one or more indicators: a list with 28 indicators was preliminarily established, e.g. Vehicles/km to illustrate the congestion, CO2 level for the quality of the air or degree of acceptance for safety, etc. [7] (see Fig.2 for one example).

2.2 Car-sharing project

In 1999, La Rochelle introduced an electric car-sharing system (“LISELEC” project) (Fig.3).



Figure3: Car-sharing system in La Rochelle (Fr)

The system was devised by a grouping set up jointly by La Rochelle Urban Community, VIA GTI, PSA Peugeot Citroën, Alcatel CGA Transport.

This type of service is generally organized as follows:

Human resources: the manager of the system supervises the activity of 2 commercials (persons in charge with the relations with the subscribers) and of 5 workmen (jockeys) ensuring balance between the stations, the operations of maintenance such as the load of the electric vehicles, the process of cleaning, repairs, the follow-up of the technical control.

Users: The customers of the service are citizens who subscribe a subscription to use a car. The customers and the jockeys will receive a smart card which gives them the possibility of using the car according to authorizations.

Technical resources: the service offers 50 electric cars adapted to the urban traffic and for short voyages. The electric cars are distributed in several stations located in the strategic points of the city. The number of places by stations can vary between 8 and 18. An information processing system is embarked in each vehicle to provide the interface between the user (jockey or customer) and vehicle. It memorizes information (hour of loan or hour of restitution, user ID, numbers kilometers, state of load of the Ni-Cd batteries, for example). This information transmitted by hertzian way to an information processing system located on each station is transferred through a telephone line to the central station. The central station can emit alarms according to various criteria; for example if the number of cars available in a station is lower than two, or in the event of non-payment of subscription. This system manages all the information about the fleet and the customers and can act on the availability of cars such as holding a car for maintenance actions.

Fig.4 shows the actors of this service and the interdependences between the entities.

Since 1999, LISELEC has been entirely managed by the La Rochelle Urban Community, which financed the difference between subscriptions and revenues, and the exploitation costs.

Experimentation was successful but difficulties appeared:

- Specific maintenance problems occurred, information system begun to become obsolete,
- Demand satisfaction was limited by administrative rules,

Extension over the city needed to increase subscriptions and usage of vehicles.

Furthermore, it turned out that the current equipment (software, control system) do not provide a sufficient quality of services.

Within CIVITAS-SUCCESS, the Urban Community took the opportunity to strongly change/improve the car-sharing system (see <http://www.comox.fr/1/101.aspx>).

- Several improvements have been implemented thanks to the introduction of a new supervision system EILEO (based on GPRS localization) and to the adaptation of standard software to the specific requirements of LISELEC.

- In addition, new services are now available for the subscribers like: access to a 24/7 hotline available not only by phone but also directly from the cars (including real time route guidance), Internet booking facilities, newsletters for subscribers.

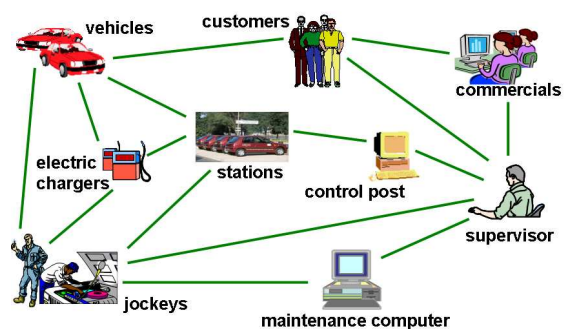


Figure4: Actors and interrelations of LISELEC

Results are globally positive. Fig.5 and Fig.6 show the gain in fuel consumption attributed to the use of the system car sharing. The algorithm to compute the gain in fuel consumption/month and NOx saved is based on the COPERT III methodology.

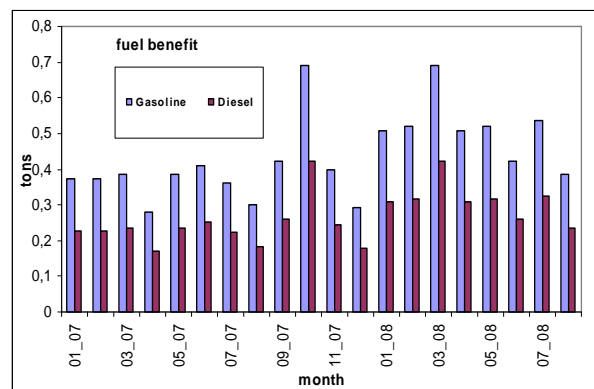


Figure5: Gain in fuel consumption (per month in tons): July 2007 – August 2008

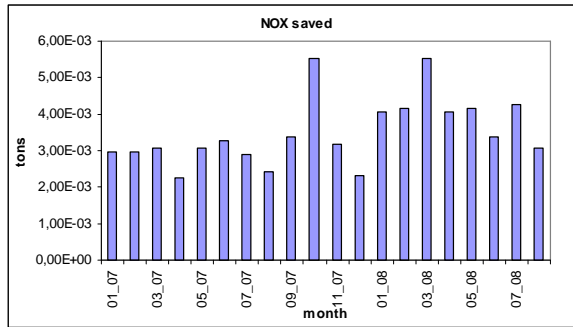


Figure6: Gain in NOx (per month in tons):
july 2007 – august 2008

More than 40 % of people without subscription pointed out the fact that stations were not implemented near their residencies.

3 Extension of car-sharing in medium sized cities

3.1 Up-scaling of LISELEC service

Main objective of SUCCESS is to propose to decision-makers approaches and tools in order to ensure successfully the transfer of these innovative projects at large scale or in other European cities.

Up-scaling provides an estimate of what the impacts of a measure (or group of measures) would be if it/they were implemented fully throughout the city. It provides guidance to the city about further deployment and to other cities in Europe which may consider implementation of the measure(s).

For the car-sharing service in La Rochelle, several studies were conducted:

- simpler pricing strategy to meet as much as possible the customer's needs: adapted pricing offer distinguishing "one way" and "return" trips; subscriptions for short or long duration, in connection with other transport modes of La Rochelle Urban Community,
- integration of the LISELEC ticketing system in the global ticketing system of the public transport network,
- extension of the stations number and creation of a virtual station mode for the whole hyper centre of the city.

3.2 Extension of the car-sharing service

Several approaches have been developed to implement car sharing systems. One of the most well known comes from the MOSES project but

specific methods are also used by car sharing companies like Mobility or Cambio [10], [11]. All are adapted to a specific local context quite different from the one of French medium sized cities in 2005. According to Bach [12], the parking location problem shall be firstly based on the consideration spatial behaviour pattern. The spatial behaviour patterns are those spatial links that arise when users have to go to the location for the purpose of consuming infrastructure services or when infrastructure services are distributed by the suppliers to the locations of users. A dedicated approach has been designed for La Rochelle. This method is based on a multi criteria analysis and takes into account not only the demography but also economic activities (see Fig.7).



Figure7: Localization of the existing (in blue) and future stations (in red)

Now the problem is the classification of the stations, in agreement with the needs of potential users. The efficiency of this type of service strongly depends on the use rate.

4 Proposal of one approach to select new Liselec stations

4.1 Choice of a method to model the preferences

In general, travellers will choose the action that maximizes their perceived utilities.

For local travellers, behavioural models are typically calibrated by using the observed preferences. But the database must be exhaustive in order to capture significant statistical information. The observed preferences are not useful when the number of customers is lower than 300 subscribers for the small cities. For it, we considered that in our case, the modelling of the stated preferences remains the most efficient tool. Many techniques of advanced behavioural modelling have been developed past years in order to integrate the heterogeneity of preferences [13].

Since several years, a new generation models based on fuzzy logic [14] have been developed in order to capture the inherent vagueness in human perception and appreciation of attributes of trip chain. The experiences with the application of fuzzy logic in traffic engineering seem beneficial to a number of applications, especially in the human choice and decision processes (see [15] for a good state of art). The difficulty of this method is to establish the decision rules IF-THEN. Theoretically, ideal approach is to consider all the combinations of the variable's levels, but that leads to an exhaustive explosion of number of rules. In our case, that would lead to a very high number of questions to submit to the subscribers. Let us suppose a questionnaire to examine the effects of the variation of 5 input variables, each one on 2 levels. In this case, 32 questions would be necessary for this kind of analysis.

4.2 Steps of the selection approach

Fig.8 presents the main steps for the extension of the car-sharing service. Next paragraphs will present briefly the mathematical approach for the modelling of preferences and estimation of the use rate (see our previous works [16]).

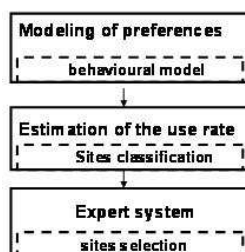


Figure8: Main steps of our approach

4.2.1 Step 1: Modelling of preferences

The database will be collected by stated preferences of people living in the proximity of pre-selected locations for the car-sharing stations. The decision criteria for locating car-sharing stations were selected by literature review on car parks [17]. The retained input variables and which will be fuzzified (trapezoidal form) are: price of subscription/month (A), distance on foot house-station (B), average length of the travel (C) and number of persons in the car (D). Each input variables has 3 levels: low, intermediate, high. The expected response is a score (range 1 to 9 in our case, in order to illustrate the interest for the displacement by using the car-sharing service). Two modalities exist for the output variable (response).

To collect the preferences of users, a method generally employed for optimisation of industrial process has been used in order to reduce the number of scenarios to test. This approach is organised in two steps:

- Collection of preferences for a part of scenario:

An orthogonal factorial design is a subset of a complete array [18]. To study jointly the effects of the criteria and the interactions, the questionnaire must contain particular combinations: each level of each criterion must be present in an equal number of times as well as each combination between the levels of two distinct criteria. In each scenario, the simultaneous variation of several criteria in input can lead to interactive effects on the studied answer. An interaction between criteria exists; when the effect of a criterion depends on the level of another criterion (for example a low price and a low distance could have a positive impact on the perception of the choice of this voyage).

Table1: a part of questionnaire

Variable	A	B	C	D	Score
Question	price of subscription/month (€)	Distance to walk to the station (metre)	average distance of the trip (km)	number of persons in the car	Interest degree (score in the range 1-9)
1	Low (1-7)	low (0-100)	low (0-2)	low (1-2)	9
...
5	Intermediate (8-9)	intermediate (100-200)	Higt (2-5)	Low (1-2)	4
...
9	hight (10-12)	hight (300-500)	intermediate (2,5)	low (1-2)	1

Table1 shows 3 scenarios tested among nine. For example, the first question is: “IF the price is low, IF the distance is low,...THEN my answer is 9/9”. The answer is a score in the interval 1-9 (and translates, in the growing direction, the degree of interest for the use of a car-sharing).

• Modelling of preferences for untested scenario:

In order to establish the scores for all the untested scenarios, we used the principles of the models of discrete choices [Ben-Akiva1999]. In general, travellers will choose the action that maximizes their perceived utilities.

The utility function is the sum of two components:

$$U_{in} = S_{in} + \varepsilon_{in} \quad (1)$$

S_{in} , a deterministic part is related to the characteristics of the alternative I (in our case called score);

ε_{in} is a random variable of unknown value, which reflects the particular opinions (not measured) of each person, as well as the observation or errors of measurement made on the characteristics explicitly taken into account in S_{in} .

Each customer has his own model. Thus one obtains, with only 9 questions, the set of 81 rules IF-THEN to prepare the table of inference for each customer. For all scenarios, the manager is able to know which could be the potential attitude of each subscriber: The variables are fuzzified (trapezoidal form), inference table is used in order to estimate the variable output, in our case the preference degree, in fuzzy form. For the variable output, two levels have been defined: very interested and not interested.

After the application of the fuzzy logic, for each respondent, we can have 2 different situations:

- the person is decided (the membership degree is 1 for one of the modalities: “very interested” or “not interested”)
- the person is undecided (the output variable is distributed on two modalities).

4.2.2 Step 2: Estimation of the use rate

Now imagine that we must classify several pre-selected sites in order to implement a car-sharing station.

The aggregation of the database will be done by using the theory of evidence that is a framework for representing the uncertainties [20], [21].

The Transferable belief model represents quantified beliefs based on beliefs functions. Let

θ be a finite set of mutually exclusive and exhaustive hypotheses H_i , called the frame of discernment.

$$\theta = \{H_1, H_2, \dots\} \quad (2)$$

The power set 2^θ contains singletons hypothesis as well as disjunctions of singletons. A Basic Belief Assignment (BBA) is a function called mass (m) from 2^θ to $[0,1]$ verifying:

$$m : 2^\theta \rightarrow [0,1]; \quad \sum_{A \in 2^\theta} m(A) = 1 \quad (3)$$

It represents the belief exactly associated to the hypothesis A. The subsets A of θ , such that $m(A) > 0$, are called the focal elements. In fact, if the power set contains only the singletons, the mass is the classic probability.

Let Ω be a finite set of hypotheses mutually exclusive and exhaustive called the frame of discernment. In our case $\Omega = \{\text{Not interested, Very interested}\}$. Generally the mass assignment is the most critical stage and it depends on the application domain.

In our case, the mass assignment is based on the frequentist analysis. By using results of behavioural models, for a given station S_i we can obtain, for the tested scenario: n% persons for « very interested »; p % for « not interested »; and q% for « undecided».

The mass assignment is $m(\text{very interested}) = n$; $m(\text{not interested}) = p$; $m(\text{undecided}) = q$. Beliefs are transformed into a probability measure denoted $BetP$ [22] which is defined as:

$$BetP(A) = \sum_{B \subseteq \Omega} \frac{|A \cap B|}{|B|} \times m(B), \quad \forall A \subseteq \Omega \quad (4)$$

$|B|$ denotes the cardinality of the set B.

For each station we will compute a utility function as proposed in [23]:

$$u_{betP}(S_i) = \sum_{i=1}^m u(H_i) \times BetP(H_i) \quad (5)$$

where $u(H_i)$ is the utility of an hypothesis which can be obtained with a linear function. In this case,

$u(H_{i+1}) \geq u(H_i)$ if H_{i+1} is preferred to H_i . If

$u_{betP}(S_i) \geq u_{betP}(S_j)$, then the station S_i is preferred to station S_j .

4.2.3 Step 3: Expert system

The architecture for the decision tool that is under development for the site selection of the car sharing station is schematically presented in Fig.9.

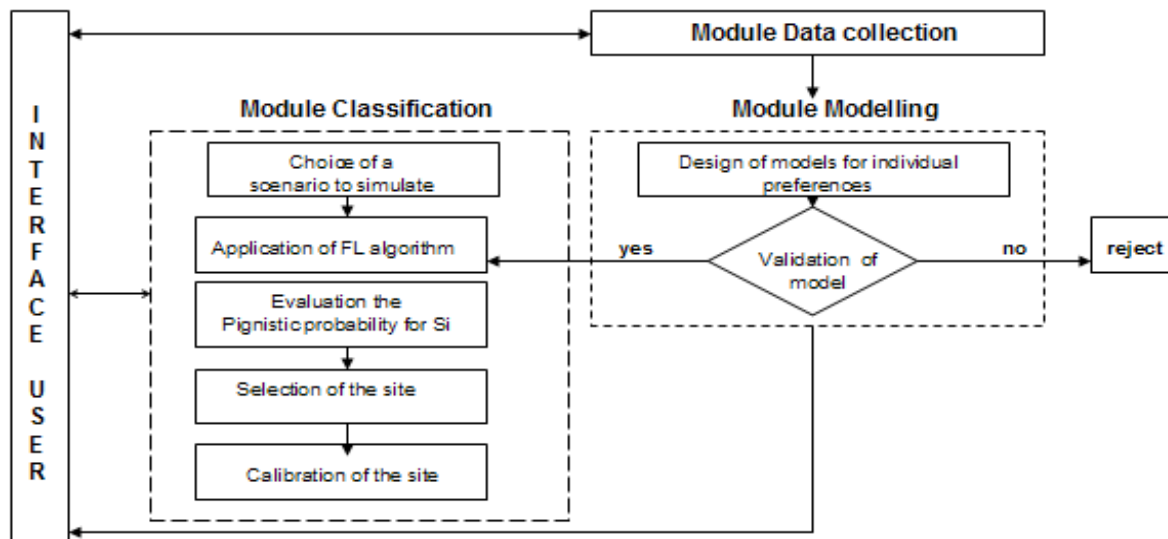


Figure9: Modules of the site selection process

By using this system, the decision maker can test scenarios: price of the subscription, distance on foot (by using a GIS module and the address of the potential subscriber), length of the trip and number of person in a car.

A behavioural analysis can be performed in different ways:

- to establish which are the parameters the most pertinent in the choice of the car-sharing service;
- to classify the customers in different categories by using statistical means such us PAC (Principal Component Analysis).

5 Conclusion

This work focused on the description of a hybrid approach for the selection of the stations for a car-sharing service in a small city. The criteria to classify the potential stations are based on the analysis of the preferences of the habitants of each urban area. The preferences are collected by using orthogonal arrays and have the advantage of a low number of questions with respect for the private life. The IF-THEN rules that alimented a fuzzy logic algorithm are captured by modelling the preferences of the respondents. The classification of the sites is performed by using the pignistic probability, after the aggregation of the results. The implementation of the algorithm in an expert system can be used in complement with the knowledge of specialists and can be very useful for the decision makers (urban planners, local authorities) because of the important number of simulations. This kind of method and

tool can be used to study the locations for bus station or for the implementation of a bike-sharing service.

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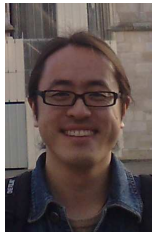
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