Optimisation of car fleet exploitation using statistical and fuzzy logic approaches

J. M. Boussier\textsuperscript{1,2}, L. Ion\textsuperscript{1}, D. Breuil\textsuperscript{1} & S. Benhabib\textsuperscript{1}
\textsuperscript{1}D\textsuperscript{é}partement LOI, EIGSI, Ecole d'Ingénieurs en Génie des Systèmes Industriels, La Rochelle, France
\textsuperscript{2}Laboratoire L3I, Université ULR, La Rochelle, France

Abstract

LISELEC is a car sharing system implemented in La Rochelle in 1999. Its goal is to provide the city with a clean transport means offering a mode combining the individual use and the public ownership. This paper presents our contribution to develop a decision aid tool with a double objective: to optimize its exploitation and to anticipate extension (increase of the number of stations or cars, change of vehicle type) for improving the system efficiency. The first step of this project was a detailed analysis of the data exploitation for acquiring knowledge of components behaviour. In this aim, Principal Component Analysis was used to establish correlations between different vehicles flows, departure hour and arrival hour. Via concepts like accessibility and attractiveness of an urban area, a fuzzy logic approach was used in order to model the flows between the Liselec stations.

Keywords: urban station, fuzzy logic, principal component analysis.

1 Introduction

The continuous increase of the number of vehicles has caused a tremendous growth of the traffic flows on public roads, especially in urban areas; saturated car parks, congested roads, environmental effects explain that the local authorities have look for alternative mobility solutions in order to satisfy users and environmental strategies.

Modelling and simulation techniques are frequently used to understand the traffic problems at different levels of abstraction and to help in easy understanding for various managers who have different knowledge of the
considered phenomena. They are also useful when the effects of implementation of a policy are difficult to predict and when the implementation of the policy is expensive.

2 Liselec service

2.1 Liselec principle

In order to improve environment policy and to solve the accessibility problems in strategic points of the town, an electric vehicle car sharing system has been implemented in La Rochelle in 1999. Liselec is a service with 50 electric cars which is adapted to the urban traffic and for short travels. All people who need a car (local or visitor) could use it after subscription. The customers receive a smart card which gives them the possibility to use any free car at any time.

2.2 Liselec description

The electric cars are heterogeneously distributed in seven stations located at strategic corners in the city flows (fig.1).

![City center](image)
![Campus](image)

Figure 1: Two main poles constituted each one with two stations are pointed out.

The number of places at the stations varies between 8 and 18 places. A computing system is embedded in each vehicle to ensure the interface between the customer and the car. It also stores all events (borrow hour or restitution hour, user identification, number of kilometers, state of the batteries charge, e.g.). A software system in each station communicates with the cars via a phone.
link and transmits information to the central control via a modem. The central
control can fire alarms according different criteria; for instance if the number of
the available cars in a station is lower than two or if the station is in over
saturated then people have to be sent for taking cars in or away. This
management system stores all information concerning the fleet or the customers
and may act on the cars availability such as blocking a car needing maintenance.

3 Management problematic

3.1 Short time activities

The localisations of the stations were thought so that all possibilities of
pendularity in travels were avoided such as travels between work/home or city
centre/suburban hypermarkets. That is why it is difficult to suggest comportment
laws associated to customer's habits. This lack of anticipation leads to several
problems in short time activities concerned with the balancing of vehicles in the
stations. These balancing activities are made by persons called "jockeys" and are
realised on the basis of human experience and real time analysis of the status of
each station. Figure 2 shows a typical example of a station where the difference
between the in and out cars is calculated every 15 min; since the number of
available places of this station is limited to 12, the intervention of the jockeys
was necessary at 10 am and 1 pm.

![Figure 2: Unbalance state of a station for a day.](image)

Even if data and information relative to the fleet exploitation are correctly
stored and can be analysed for a better knowledge of the system functioning, the
lack of medium (long) term planning induces several dysfunctions for the
balance activity.
In order to predict the stations activity and the flows distribution it should be desirable to accommodate the number of the available cars for each station with different behaviours and heterogeneous destination of each customer.

3.2 Long time forecast

Because of the complexity of the system, another problem is to imagine the Liselec extension (opening up new sites, implementing a system of reservations, accommodating the number of vehicles). Which are the criteria to choice the number of new stations, their geographical position or the number of available places for each station? How to predict the different impacts on the overall system (flows redistribution, number of customers, e.g.)?

One solution to help management and forecast problems solving is to develop a decision aid tool able to anticipate the flows using the urban area characteristics. Indeed, the customer's habits are depending on the socio-economic and pleasure activities bounded to two time-space concepts: the attractiveness and the accessibility of each city zone.

4 Approach for a decision aid tool development

A presentation of a global approach to develop the decision aid tool is presented in fig. 3. Conceptual modelling, implementation and software development must be seen as a cyclical process and each step has a validation phase. Modelling and simulation are crucial steps for a decision aid tool development. Our paper is focused on the conceptual model elaboration of the vehicles flows.

Figure 3: Modelling and simulation steps.
4.1 Current modelling approaches

Various traffic models describing the vehicles flows (see Sarramia [1] for a detailed overview) have been developed. Their differences lay in:

1. the expected goals (local, as the regulation of local traffic or general, as the urban development in accordance with transportation system)
2. the employed techniques (mathematical approaches, oriented-object tools, e.g.)
3. the granularity level (macroscopic, microscopic or mesoscopic description)

But, most of these models are built on mathematical approaches which cannot incorporate uncertainties and inconsistencies as behaviour aspects. The variables in these models are easy to quantify (number of vehicles, origin-destination matrix, e.g.). Whereas, attractiveness and accessibility, which are basic components in destination choice are illustrated by semi-empirical formula frequently based on socio-economics considerations (Hess and Polak [2], Bonnafous [3], Hasson [4], Joerin et al [5]).

4.2 Approach based on fuzzy logic

The fuzzy modelling techniques seem to us to be an adequate tool to describe behavioural processes with uncertainties variables. It is a tool to describe and to process information about systems of interest using everyday spoken language. The logic fills ambiguous qualifiers that human experts use with crisp mathematical models so they can be used by computers (Zimmermann [6]). Some empirical research with fuzzy logic has been done on modelling individual driving behaviour and traffic conditions (Dell'Orco and Sassanelli [7], Naranayan et al [8], McDonald et al [9]).

In order to describe the vehicles flows, we propose first a model to evaluate an indicator that we will name "affinity" between two stations as function of the accessibility to an urban area, the attractiveness and the cost of the travel between these two stations.

The principal steps are schematically presented in fig. 4.
4.2.1 Knowledge of system

More than 50,000 acquisitions stored for two years were exploited using SQL requests. Detailed results concerning the users' profile, their behaviours, and the flows distribution for the seven stations were presented in our previous works (Breuil et al [10]). This study revealed interesting behavioural aspects and pointed out the necessity to search correlations between different variables (departure or arrival hours, customers domicile, number of movements, etc.). In this aim, we have used Principal components analysis (PCA) approach. It simplifies the dataset by plotting multidimensional relations in two-dimensional space, with a great facility of interpretation.

An example is presented in Fig. 5; this figure represents the PCA analysis results of the number of vehicles entering in the stations all Wednesdays of the year, every 15 minutes (the origin station is S5 and the destination stations are the other ones). We can remark that 89.9% of the total inertia is contained within the first two components and the greatest part (85.4%) of it is already represented by the first principal factor. The contribution of the S3 data to this one is the most significant. It means that Wednesday, the activity of station S3 is a significant temporal indicator of all the fleet activity which is interesting information for the human resources management.

Our principal result was to establish a strong correlation between the customer's houses of the destination station and the number of displacements between this station and the other ones. This conclusion permits us to establish a link between the "affinity" and the number of customers of an area in order to
define the vehicles flows. Indeed, in agreement with socio-economists works in migration problems we can usually consider that the flow between two regions is depending on the number of persons who live in the origin zone (see Bonnafous [3] for a good overview); in our case, it is the number of customers which must be taken into account and this reasoning is in good agreement with the PCA results. We have considered that the number of travels between two stations can be evaluated as follows:

\[ T_{ij} = k \times n_i \times A_{ij} \] (1)

where:
- \( T_{ij} \) : number of travels between the station \( S_i \) and the station \( S_j \)
- \( n_i \) : number of customers living in an area centred on \( S_i \) (< 500 m)
- \( A_{ij} \) : affinity between the park \( S_i \) and the park \( S_j \) estimated by fuzzy logic
- \( k \) : a constant to calibrate

4.2.2 Fuzzification

To express imprecision in a quantitative mode, it introduces a set membership function that maps elements to real values between zero and one (inclusive); the value indicates the "degree" to which an element belongs to a set. A membership value of zero indicates that the element is entirely outside the set, whereas one indicates that the element lies entirely inside a given set. In our case, the trapezoidal representation was chosen. Table 1 lists the fuzzy sets used to evaluate the affinity which motivates a user to realise a travel between two stations.

<table>
<thead>
<tr>
<th>input</th>
<th>output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attractiveness</td>
<td>Accessibility</td>
</tr>
<tr>
<td>great</td>
<td>easy</td>
</tr>
<tr>
<td>moderate</td>
<td>medium</td>
</tr>
<tr>
<td>low</td>
<td>difficult</td>
</tr>
</tbody>
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The membership functions of the fuzzy sets need to be defined in order to estimate where sets begin or. The cost levels were estimated with the shorter distance between two stations; the range is 2 to 12 km. In our works, the accessibility is depending on the geographical position of the station and the average time of the travel joining two stations. The attractiveness is calibrated using the number of attraction points of an urban area of the destination station (shopping, hospital, administrative buildings, e.g.). These two variables are defined on the range 0 and 26 (5 values each one).

4.2.3 Rule base

Input of the new "fuzzy variables" into a rule base is considered according to a predefined weighting scheme in order to determine a most likely course of action. This system of rules is defined by using the experience of the expert and it is one of the most delicate steps in the fuzzy logic application. Classical statistical analysis led us also to establish the truth rules for the inference step.
A typical fuzzy rule for the affinity evaluation has the form "if the accessibility is easy and the attractiveness is moderate and the cost is high then the affinity is medium".

4.2.4 Inference
As inputs are received by the system, inference evaluates all the IF THEN rules and determines their truth values. Different fuzzy rules might have different conclusions, so it is necessary to consider all rules. It must combine all fuzzy conclusions obtained by inference into a single conclusion.

4.2.5 Defuzzification
Converts the fuzzy value obtained from composition into a "crisp" value; this process is often complex since the resulting fuzzy set might not translate directly into a crisp value. We have used the centre of gravity method.

5 Testing of the model

This approach was applied for the seven stations in order to describe the affinity between all couples of stations. An example is presented in Fig. 6.

Figure 6: Evaluation of the affinity between the destination area zone centred on station S3 and the origin station S7.

Generally we have obtained a satisfying agreement between the measured values of the number of travels between two stations and the values estimated using the fuzzy logic. We can note that the model is perfectible because attractiveness degree and accessibility values modify for the weekend, according to the season or the number of customers. Fig. 7 presents an example allowing to see the distribution of the flows in a year which has as origin the station S7. The figure b) concerns the analysis of all weekends: the accessibility was estimated by using the mean time of travel corresponding to all Saturdays and Sundays and the attractiveness was evaluated according with the attraction points opened the weekend in each city zone.
6 Discussions and perspectives

Because of the complexity of our system, the Fuzzy logic incorporated an alternative way of thinking, which allows a high level of abstraction originating from our knowledge and experience. Used for a decision aid tool development, this approach is like human decision making with its ability to work with approximate heterogeneous data and find precise solutions. We have remarked a good agreement between the measured values of the vehicle flows and the results obtained with the Fuzzy logic. A better knowledge of the behaviours of the Liselec users and of the activities planning of La Rochelle should permit a preliminary fuzzification of variables like the accessibility and the attractiveness in order to affine the results and the interpretation.

Except the number of the customers, the model do not use any other variables which must be previously known; that is why, this approach could be interesting in order to have an overview of the activities of the parks, of which lack is the principal difficulty to manage or to develop this system. It is also possible to analyse the redistribution of the displacements with the modification of the number of the customers or with the implementation of new Liselec stations.

But the decider wants also to be able to make decision to adjust the equilibrium in each station in order to satisfy customers and to plan the jockeys' activities (service persons affected to the Liselec system). In this aim, a daily management involves to complete the model. Supplementary variables as the type of hours (illustrating the congestion degree during a day) must be introduced for better describing the accessibility concept as a time-space phenomenon (Hasson [4]). One the other hand, a further more detailed analysis using the Principal Component Analysis will surely affine the truth rules.

These preliminary works are included in a general project (Augeraud et al [11]) where we consider that an urban traffic network can be modeled using the multi-agent technology (Boussier et al [12]). The fuzzy logic seems to be an appropriate method to develop a traffic model by the "car following" approach and also to develop scenario to test the software system.
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