Improvement's methodology, under uncertainty, of the management of a public transportation service

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Abstract: To be attractive, a self-service public transportation (bicycles or cars) have to ensure to the subscribers a degree of availability without fault. Our work is focused in the development of a methodology to aid decision makers to ensure the balance between the stations, to test new locations for the car-sharing stations. This work proposes a hybrid method based on concepts resulting from fuzzy logic, optimization and the theory of the beliefs, making it possible to model the preferences of the subscribers and to determine the maximum utilization ratio of the stations. The manager of a car-sharing service can based on this step for better planning the activities of his team and to reduce the cost of unavailability and the exploitation. Performance indicators are defined for it and the optimization is based on the modelling of preferences of customers.

Key-words: car-sharing, grid GRAI, use rate of a service, customers' needs, fuzzy logic, uncertainty

1. Introduction

During the last few years, in agreement with the evolution of urban mobility, engineers, specialists in regional planning, socio-economists and local authorities have agreed to a common strategy: to develop urban transport systems ensuring good conditions of accessibility, without neglect the environmental impacts as well as social and financial constraints.

This work has been done in the framework of SUCCESS European project (Smaller Urban Communities in Civitas for Environmentally Sustainable Solutions) [12]. 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. Their principal targets are:

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.

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

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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.

But to provide good interoperability between public transport and car sharing vehicles, it is essential to place the stations in adequate places and to ensure the balance between stations. Car-sharing systems are most successful there where is sufficient economic and social activity and where that activity has a strong relationship to public transport. Several 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. Generally, studies and surveys confirmed that the land use, the population density and availability of public transport are key considerations to implement and to calibrate a car-sharing system. These conditions are not easy to accomplish in small cities (<120000 habitants), even if cities such as La Rochelle France can be a positive example [6]. Local authorities of small cities are generally reticent for implementing it because of the difficulty to calibrate the car-sharing stations (location, number of cars) as well as to manage it (balance between cars for all stations during a given period). Few researches works focuses on this problem [10]. 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 [1] 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. Criteria such as the demographic level, the number of attractiveness points are frequently tested in Analytic Hierarchy Process [2].

For the balance between stations, there are few studies that simulate the activity of the fleet of a car-sharing service [3].Our work is focused in the development of a methodology to aid decision makers to ensure the balance between the stations, to test new locations for the car-sharing stations. Performance indicators are defined for it and the optimization is based on the modelling of preferences of potential customers. The main principle is to understand and to exploit the customer's preferences, even in a fuzzy manner, in order to anticipate the customers' needs.

Section 2 presents difficulties to manage a car-sharing service. Section 3 shows the method for modelling the behaviours. The method to aggregate and to exploit information to optimize and test new scenarios is presented in section 4. Section 5 introduces performance indicators and shows how our approach can be exploited to optimize the management of the car-sharing service. The final section outlines the conclusions and the perspectives of our work.

2. Management of a car-sharing service in small cities

2.1 Description of the service
This type of service is generally organized as follows (figure 1):

Human resources: the manager of the system supervises the activity of several commercials persons (in charge with the relations between service-subscribers) and of several workers (jockeys) who ensure the balance between the stations, the operations of maintenance such as the load of electric batteries, the cleaning, repairs, the follow-up of the technical control.

Users: The customers of the service are citizens or companies who detain a subscription. The access to the car is ensured by a smart card.

Technical resources: 50 electric cars adapted to the urban traffic and for short trips are distributed in several stations located in strategic points of the city. An information processing system is embarked in each vehicle and provides the interface between the user (jockey or customer) and the vehicle. It memorizes information (hour of loan or restitution, user, kilometres, state of load of the batteries, for example).

This information transmitted by hertzian way to an information processing system located in each station is transferred through a telephone line to the central station. This system manages all the information about the fleet and the customers and it can act on the availability of cars such as holding a car for maintenance actions.

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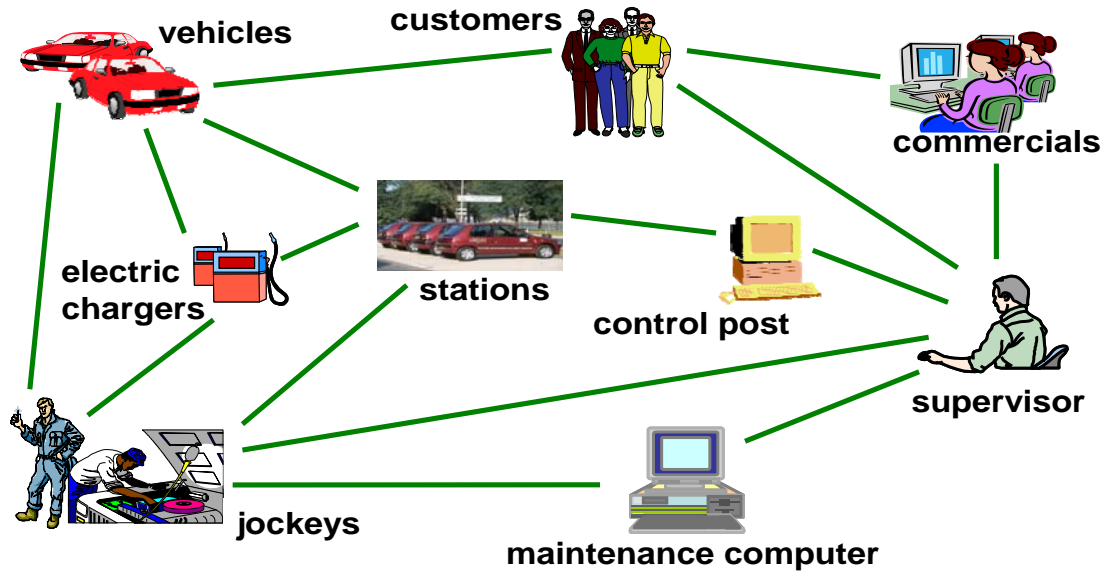Y. Ducq, Augustin Mitu

Fig. 1 Description of the service [5]

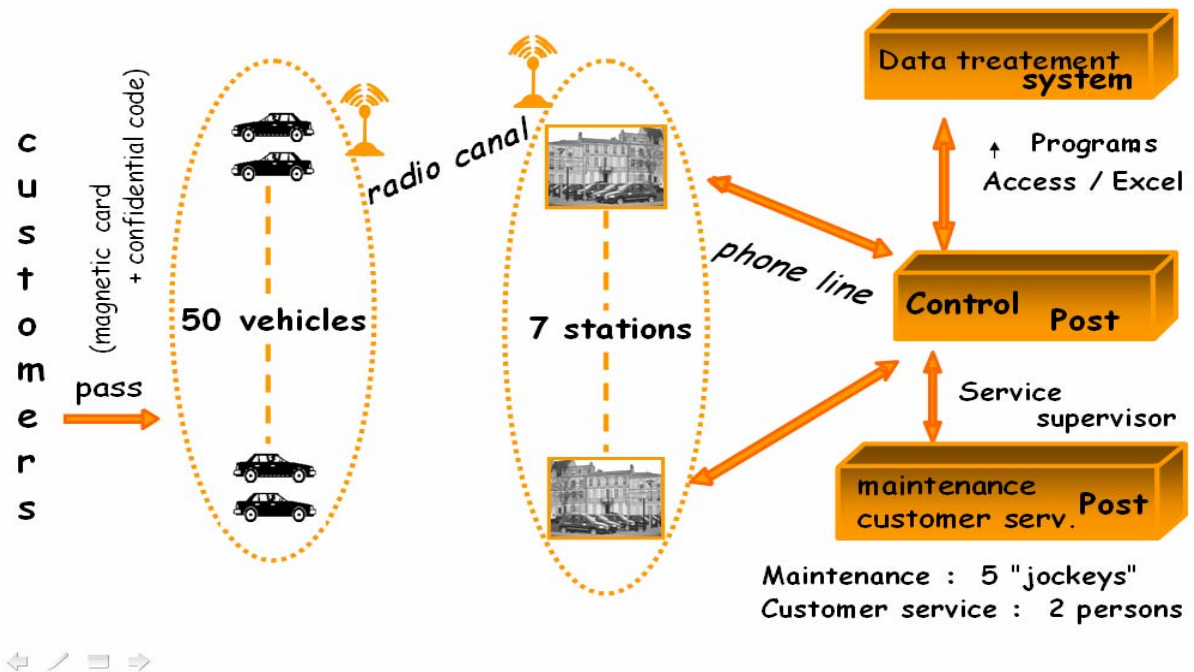Figure 2 shows the simplified schema for communication between the actors of the car-sharing service.

Fig. 2 Communication system

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	External information E	Commercial and marketing management F	Sales administration F	Equipment management F	Planning F	Maintenance management F	Humain ressources management F	Internal Informations II
H=3 year P= 1 year	Investigation of customers	Analyse customers trends		Strategic planning of vehicles acquisition	Budget			
H=1 year P= 6 month		Determine maine marketing elements. Adjust marketing plane					Estimate required amount of jockeys	
H=6 month P=3 month		Define publicity compaigns				Forecast servicing activities		
H=3 month P=1 month		Follow turnover	Manage subscriptions				Estimate required « humain » capacity	
H=3 day P= 1 day			Solve bad uses consequences	Forecast equipments availabilities at stations	Exploitation Planning	Plan full reloading of batteries	Allocate tasks	
Real time			Establish contracts	Ballance vehicles on stations	Organization of the rounds on the stations	Verify vehicle, clean, repair	Adjust allocation according real state	Real state of vehicles

Fig. 3 Grid GRAI for a car-sharing

2.2 Management process

Grid GRAI was used to underline the forces and the weaknesses of the service by including all the aspects of operation, the commercial activity until the maintenance activity (fig.3).

We notice several problems in the activity of the service:

• There was no planning activity on medium or long term decision level. The lack of anticipation of demand leads to several problems in short term activities about the balancing of vehicles in stations and the allocation of human resources;

• The balancing activities are realised on the basis of human experience of jockeys and real time analysis of the status of the stations. In the same time they are quite free to organise their job according to the state of vehicles and to decide what to do in priority (cleaning, battery refilling etc);

• Maintenance is not really planned, only servicing is anticipated. But the age of electric batteries is a critical point for the efficiency of this kind of service;

• Marketing strategy is not oriented for the extension of the system.

For solving main problems (unavailability of cars [9] during peak periods and management at medium and long term) and for testing new stations, 1 indicator has been pointed out: the number of expected cars in a station for a given period.The difficulty for evaluating and optimise this indicator is to know how many people will use the service for a given period. The knowledge of this indicator could allow evaluating the number of vehicles available (for maintenance operations or for testing another site location for a new station). Figure 4 presents the main steps of our approach who will be detailed in two next sections.
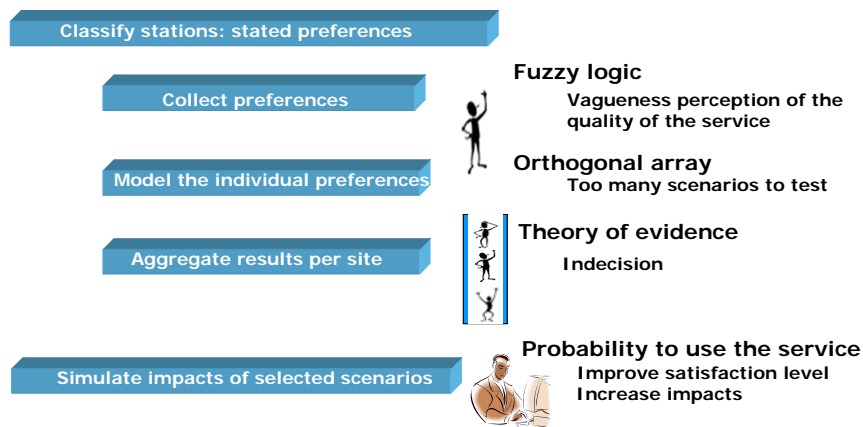
Classify stations: stated preferences

Collect preferences

Fuzzy logic
    Vagueness perception of the quality of the service

Model the individual preferences

Orthogonal array
    Too many scenarios to test

Aggregate results per site

Theory of evidence
    Indecision

Simulate impacts of selected scenarios

Probability to use the service
    Improve satisfaction level
    Increase impacts

Fig. 4 Main steps of our approach

3. Approach to simulate the use rate of subscribers

3.1. Choice of a method for modelling the preferences

Several algorithms have been developed that determine when and how relocation occurs in order to ensure balance between stations (see [3]) for a detailed review):

• Static relocation. Based on immediate needs at a particular station, vehicles can be relocated from another station..

• Historical predictive relocation. This type of relocation mechanism uses knowledge of expected vehicle demand in the future in order to determine when and from where a relocation event occurs. The predictive relocation mechanism looks approximately 20 min into the future to determine expected demand. But it is not enough for planning maintenance operations and human resources management.

Because exact knowledge is impossible to achieve in the real world, so the best that can be done is to model preferences and to define a doorstep (risk value) for the use rate of each station.

Many techniques of advanced behavioural modelling have been developed past years in order to integrate the heterogeneity of preferences [4]. A solution could be a preliminary analysis of their preferences and constraints in agreement with the characteristics of the trip (such as the period of the day, the weather etc), the characteristics of the traffic like the probable level of congestion and the average speed.

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 [8]. For several years, a new generation of models based on fuzzy logic [has been developed in order to capture the inherent imprecision in human perception. The application of fuzzy logic in traffic modelling seems salutary (modal choice, programme of activity, routes etc).

There are five principal stages in the application of fuzzy logic:
1) Choice of the input and output variables: The tested input variables are: moment of the departure, the period of the week, the external temperature, the level of congestion, the average speed for a given period. Each variable has two levels which will be specified in the following paragraph. The output variable is called "degree of interest for the use of a car" and presents two modalities (very interested, without interest);
2) Fuzzification: To represent vague information, one defines a trapezoidal function of membership; the value indicates the "degree" of membership of an input variable to a unit;
3) Fuzzy rules: A typical fuzzy rule with the form "If the departure takes place the morning, IF the trip is made the WE, and IF the temperature is 5°C,... then I am very interested to use the car-sharing". Rules IF-THEN will be the answers to the hypothetical scenarios gathered by questionnaires near the subscribers (the process of collection will be detailed in the next paragraph);
4) Inference: The inference evaluates all rules IF-THEN and determines their values of truth. The fuzzy rules could have various conclusions, thus it is necessary to consider all the rules, in order to combine all the fuzzy conclusions obtained by inference in a simple conclusion.
5) Defuzzification: it is a stage often carried out to convert the results of the inference in a numerical form (non fuzzy).

The difficulty of this method is to establish the rules of decision IF-THEN for the table of inference. Theoretically, ideal is to consider all the combinations of the levels of the variables, but that leads to an exhaustive explosion of the 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 at 2 levels. In this case, 32 questions would be necessary for this kind of analysis.

To collect the preferences of the users of the service, a method generally employed for the optimisation of industrial process have been used in order to reduce the number of scenarios to test. The application of this approach necessitates two steps:
1) Collect of preferences for a part of scenarios;
2) Modelling of preferences for untested scenarios.

3.2. Collect of preferences for a part of scenarios

An orthogonal factorial design is a subset of a complete array [13]. 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 an equal number of times as well as each combination between the levels of two distinct criteria.

In each scenario, the simultaneous variation of input several criteria can have 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 external temperature and a morning departure could have a negative impact on the perception of the choice of this trip).

Table 1 presents an example and a linear graph for the allocation of the columns (the nodes correspond to the criteria, the arcs correspond to expected interactions).

In agreement with the linear graph (Table 1), it is possible to study the effects of the interactions AG and AD.

The manager of the service car-sharing communicates to the customers the level of congestion and the average speed at the end of each week starting from the central station (by SMS or phone, for example). Because of the similarity of the weekly activities, the temporal reference is the same day and the same period of the day of the previous week. For each tested configuration (scenario) an answer is done by each customer the day of their subscription. 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).

Table 2 shows 2 scenarios tested among 8 (thanks to a subscriber): for example, the first question is: "IF the departure is in the morning, IF the temperature is low, IF it is one working day with low congestion level and low speed, THEN my answer is 6/9).

Variable	A	B	D	E	G	Score
Question	Moment of departure	temperature	Type of day	congestion /h	Average speed	
1	Morning (7h-12h)	Low (t<18°)	Working Day (M,T,W, Th, F)	Low (<400 vehicles)	Low (v<41km/h)	6
...	...	...	...	...	...	...
8	Afternoon (14h-24h)	High (t>22)	No working day (S,S)	Low (<400 vehicle)	High (V>51km/h)	5

Table 2: Example of 2 tested scenarios

3.3. Modelling of preferences for untested scenarios

In order to establish the scores for all the scenarios not-tested, we used the principles of the models of discrete choices [4]. In general, travellers will choose the action that maximizes their perceived utility (quality of service).

The utility function is the sum of two components:

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

Where 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 tastes (not measured) particular of each person, as well as the observation or errors of measurement made on the characteristics explicitly taken into account in S_{in}.

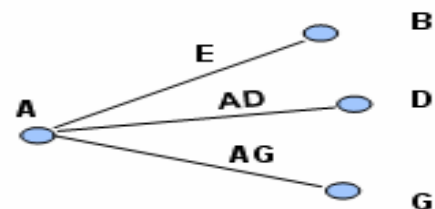| Question	A	B	D	E	G
1	1	1	1	1	1
2	1	1	2	2	2
3	1	2	1	2	2
4	1	2	2	1	1
5	2	1	1	1	2
6	2	1	2	2	1
7	2	2	1	2	1
8	2	2	2	1	2

Table 1: Orthogonal array and corresponding linear graph

The score function S_{in} can be represented using the average effects by a model as follows:

$$S = M + (a_1 \ a_2)A + (b_1 \ b_2)B + (c_1 \ c_2)C +$$

$$... + \begin{pmatrix} a_1b_1 & a_1b_2 \\ a_2b_1 & a_2b_2 \end{pmatrix} AB + ... \quad (2)$$

The average effect of an action (input variable or interaction) is an element of matrix defined as follows:

for a input variable of A,

$$a_i = Y_{moy}(A_i) - M \quad (3)$$

for AB interaction between two input variables,

$$a_ib_j = Y_{moy}(A_iB_j) - M - a_i - b_j \quad (4)$$

with a_i - average effect of variable A when it is on level i; a_ib_j - average effect of interaction AB when A is on level I and B on the level J; M - average of all the results of the plan; $Y_{moy}(A_i)$ - average of all the results when A is on level I; $Y_{moy}(A_iB_j)$ average of all the results when A is on level I and B on the level J.

The model being additive, the deterministic part of the utility corresponding to a scenario for A on level 2 and B on level 1 is calculated in the following way:

$$Y(A_2B_1,...) = M + a_2 + b_1 + a_2b_1 + ... \quad (5)$$

For the example presented above (table 2), the score is:

$$Y(A,B,D,E,G) = 4,625 + (0,125 \ -0,125)A + (0,875 \ -0,875)B +$$

$$+ (1,125 \ -1,125)D + (0,375 \ -0,375)E + (-1,625 \ 1,625)G +$$

$$+ \begin{pmatrix} 0,625 & -0,625 \\ -0,625 & 0,625 \end{pmatrix} AD + \begin{pmatrix} 0,375 & -0,375 \\ -0,375 & 0,375 \end{pmatrix} AG \quad (6)$$

It is easy to deduce that the most significant criteria for this subscriber are in the order the average speed and the type of day. In order to validate the model, 2 additional questions (scenarios not-included in the plan) make object of a comparison (score of model compared to the real score). One thus obtains, with only 8 questions, the whole of 32 rules IF-THEN to prepare the table of inference.

Each customer has his model. 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, 2 levels have been defined: very interested and not interested.

4. Approach to simulate the use rate of the service under indecision

4.1. Data aggregation for a global analysis of the fleet activity

Suppose that the manager of car-sharing system wants to evaluate the activities of the fleet for next week (peak periods, in the morning, for example). According to the time of departure, the day of the week, the weather conditions and the traffic conditions, the manager knows the preferences of the subscribers. The manager of the service knows also the addresses of the subscribers.

We consider that only one station S_i is located near the residences of the subscribers. For each subscriber, after the inference, one case can appear:
• 100% "very interested" or "without interest", in which case it is about a "sure" person.
• The output variable is distributed on the two modalities at the same time ("for example 50% for « very interested », 50% for « not interested »).In this case the person is "in doubt".

Just suppose one example: for a station Si, we can have an aggregated result as follows: 40% subscribers for « very interested »; 30% subscribers for « undecided »; 30% subscribers for « not interested ».

The theory of evidence is a very powerful technique which makes it possible to control the indecision [7], [11]. For a frame of discernment $\Omega = \{$very interested, not interested$\}$ and according to the frequentist method, a set of masse are attributed for a station S_i as follow: m_{1i} (Very interested) = 0,4; m_{2i} (not interested) = 0,3; m_{3i} (Undecided)= 0, 3.

Contrary to the baysienne theory which operates with the probability P (A) of an event A, in theory of the beliefs, uncertainty is measured in terms of credibility and plausibility.

Credibility Bel (A) measures at which point the information given by a source supports the proposal A. The credibility function (Bel) returns for any proposal A of 2Ω, the sum of all the degrees of belief placed on proposals implying A. The plausibility fonction (Pl) are a duale fonction of credibility:

$$Bel: \left| \begin{array}{l} 2^\Omega \to [0,1] \\ \forall A \in 2^\Omega, \quad Bel(A) = \sum_{\{B \in 2^\Omega / \{\emptyset\}, B \subseteq A\}} m(B) \end{array} \right. \quad (7a)$$

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$$Pl: \left| \begin{array}{c} 2^\Omega \to [0,1] \\ \forall A \in 2^\Omega, \quad P(A) = \sum_{\{B \in 2^\Omega / A \cap B \neq \varnothing\}} m(B) = Be(\Omega) - Be(\bar{A}) \end{array} \right. \tag{7b}$$

where B means the set of mass implying A; $\bar{A}$ opposite event of A.

From the mass assignments, the upper and lower bounds of a probability interval are defined. This interval contains the precise probability of a set of interest (in the classical sense), and is bounded by two non-additive continuous measures called belief and plausibility:

$$Bel(A) \leq P(A) \leq PL(A) \tag{8}$$

4.2. Classification of car-sharing stations

For each station S_i we obtain an interval [Bel; Pl] for each single hypothesis. Just imagine 2 stations S_j and S_k having the follow basic belief assignment:
For S_j: m (Not Interested) = 0,6; m (Very interested) = 0,15 ; m (θ) = 0,25
For S_k: m (Not Interested) = 0,5; m (Very interested) = 0,2 ; m (θ) = 0,3.
The intervals [Bel (Very interested), Pl (Very interested)] are: for S_j [0,15 ; 0,4]; for S_k [0,5; 0,8].

By using like decision maker indicator the maximum of plausibility, we have obtained next conclusion:
- it is probable that 80% subscribers will search a car at the station S_k and only 40% subscribers at the station S_j.

It means that for the given period, the station S_k could be probably more used.

5. Exploitation of the database for optimising performance indicators

5.1. Performance indicator exploitation in actual situation

The maximum rate for a period of the day, a day of the week, may be considered for all stations in order to distinguish those priorities in terms of balancing order, other maintenance operations and to test the implementation of new stations.

In order to illustrate it, the database from 2003 of LISELEC service (car-sharing service in La Rochelle) has been exploited. Figure 5 shows a typical example of a car –sharing station for which the difference between the entering and outgoing cars is calculated every 15 minutes. The number of places available in this station is limited to 12 and the intervention of the jockeys was frequently

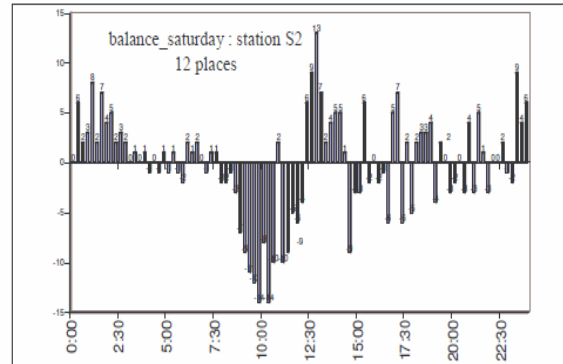necessary (not enough vehicles or too much vehicles).

Fig.5 Unbalance state of a station for a day [5]

The service contains 7 stations. Each station S_i can be characterized by the number of expected cars in a given period:

$$N_{ei} = N_a * w_i \tag{9}$$

Where N_a is the number of available cars during a given period (several minutes or hours), w_i is the weight of a station and specifies what fraction of the vehicle fleet should ideally be located at each station when there is no vehicle activity. For the electric vehicles, the weight term is determined by the number of electric connections N_i on the station. The total imbalance rate of the service T_{im} is given as a summation of normalized standard deviations:

$$T_{im} = \sum_{i=1}^{S} \left| \frac{N_{ai} - N_{ei}}{N_{ei}} \right| \tag{10}$$

And the balance can be estimated as follows:

$$BM = \frac{T_{im}}{\frac{1}{\min(wi)} + 1} \tag{11}$$

This balance measure is normalized so that BM $\in$ [0, 1]. When BM is equal to one, the system is highly imbalanced. When BM is zero, the system is completely balanced.

A vehicle in-use measure is:

$$VM = \frac{N_a}{N} \tag{12}$$

When VM is equal to one, then none of the vehicle in the system is being used; when VM is zero, all the vehicles in the system are being used.

As a final measure, it is possible to combine the effects of system balance and vehicle use in order to determine the potential for relocating vehicles.

$$TM = BM * VM \tag{13}$$

When TM is high (i.e., close to one), then the system is both imbalanced and under-utilized: therefore the vehicles should be relocated within

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the system. When TM is low, then the system is in good balance and being fully utilized.

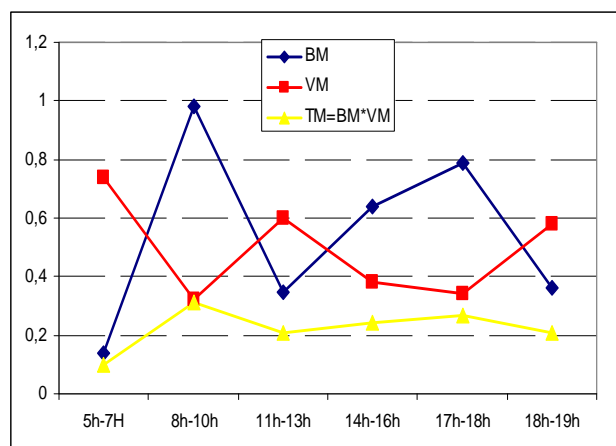Figure 6 shows the modelled state of LISELEC service (during a particular day).

Fig. 6 Indicators for balancing the service

We remark a good agreement with the experimental data, especially for peak periods.

5.2. Management improvement using our approach

This kind of service is generally unbalanced for particular periods (8 am – 9 am) or (2pm -3 pm). We consider that only one station S_i is located near the residences of the subscribers. We analyse only the departure from this station.

Suppose that the manager of car-sharing system wants to organize the activities of his team for next week.

For a given scenario (among 32 possible scenarios), for each station we can obtain a set of intervals. Each station Si obtains an interval [Beli Pli].

Different situations are possible (see formulas 9-13):

- if the service risks to be fully used (number of demands is equal to number of cars), it is possible, to perform the balance between the stations (to move vehicles from stations under-used to the station with high demands). It is also possible to inform the subscribers on the availability of a nearby station;

- if VM is low and BM low the service is globally under-used and the manager of the service can plan unused vehicles for maintenance or for cleaning activities;

- if the number of subscribers who are likely to request the services of a station would be higher than the number of vehicle (N), VM is equal to

zero. In this case the manager requires to introduce more vehicles in the system or to propose the car-pooling.

The individual models can be improved either by re-investigation or by experiences (historical data).

If the probability of choice for a given period of the day is used for each station we can calculate the number of vehicles necessary at the beginning of this period of time. The other cars of the fleet can be distributed for:

- Maintenance operations;
- Balance of the stations;
- To test the location of a new station for car-sharing.

6. Conclusions

This work focused on the description of a hybrid approach for the balance of the stations for a car-sharing service in a small city. The criterion is based on the analysis of the preferences of the customers. The preferences are collected by using orthogonal arrays and have the advantage of a low number of questions. The IF-THEN rules that alimented a fuzzy logic algorithm are captured by modelling the preferences of the respondents. The aggregation data is made using the theory of evidence in order to quantify the indecision. The plausibility is used in order to quantify the number of necessary cars for each station.

This approach allows us to ameliorate performance indicators of this public transportation service, station, such as the unavailability of cars, the balance of stations. The maintenance of cars can be optimised, as well as human resources management at medium term.

A new grid GRAI will be proposed, based on more structured processes and leading to improve the efficiency of the service. This kind of work can be done for different types of the public services, such as the Park and Ride service or bike sharing service. Our present work is focused on the development of a procedure for the extension of the car-sharing service using the same step of modelling.

This approach will be improved and tested for a multimodal optimisation of several public services (bike-sharing, park and ride and bus network).

Acknowledgments

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