DEVELOPMENT OF A DECISION AIDING TOOL FOR THE EVOLUTION OF PUBLIC TRANSPORT TICKET PRICING IN THE PARIS REGION

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Abstract

Observation of social and economic trends (falling population in the inner city of Paris, increased commuter flows between the centre and the suburbs, and demand for local ticket prices) has led the Syndicat des Transports Parisiens (STP, the Paris transport authority) to re-examine the ticket price system as it is today. Reform of this system will involve a great many stakeholders in the transport world, whose interests are not necessarily the same; they must participate in this project so that a future ticket pricing structure will be acceptable to all. Therefore all those involved must be able to take part in the study which will precede the decisions.

With this in mind, the STP has called for a methodological study which will allow the impact of ticket price changes based on zoning to be evaluated. The main lines of research concern three phases:

- Definition and evaluation of zoning choices in the Ile de France,
- Quality analysis of potential offer and demand in the zones thus selected,
- Evaluation and comparison of the various ticket pricing hypotheses.

This methodology will take the form of software which will be the basis for analysis and dialogue between the stakeholders involved in ticket price changes. This software must allow first, input, evaluation, modification and comparison of zoning choices, and second, the transport offer and the potential demand for each zoning choice to be analysed in order to design and evaluate the impact of a ticket pricing scenario applied to the zoning choice on the basis of hypothetical traffic flow evolution.

Keywords : Public transport, ticket-pricing, multiple criteria decision aiding, concertation, geographical information system.

1. Introduction

The ticket pricing system at present in force for Ile de France transport seems to be discouraging rather than attractive to customers, for the range of tickets does not correspond to their expectations. At present, there is a heterogeneous collection of tickets, prices of which seem to correspond solely to distances covered. Moreover, the zones covered by the "carte orange" season ticket no longer correspond to travel patterns. Recent surveys have shown that customers need more individually tailored, flexible tickets for their journeys. This trend intensifies the further one travels away from the capital. In addition, revenue from customer payments is far from adequate to cover the operating costs of public transport companies.

These observations of the current position have led the Syndicat des Transports Parisiens (STP, the Paris transport authority) to set up a study of the public transport ticket pricing system in the Ile de France region. This ticket pricing reform will involve many stakeholders in the decision-making process: transport companies, tutelary and organising authorities and others.

In this region, it must not be forgotten that eighty private companies run road transport services in the Ile de France, in conjunction with the RATP (Paris Metro) and SNCF (French railways). The environment of this reform will therefore be multi-institutional since it concerns both public companies (the RATP and the SNCF) and private ones, under the supervision of the STP which is under the State. The great number of stakeholders will necessarily mean concertation in this ticket pricing reform.

The main aspects of study into this reform will be in three phases (cf. Figure 1) :

- Ø Definition and evaluation of zoning choices for the Ile de France. This first phase will see zoning choices treated independently of the ticket price bases they will justify. The goal is to arrive jointly at one or perhaps several zoning choices, which will correspond to customer perceptions of their travel patterns and which will constitute an appropriate justification for prices.
- Ø The second phase will be quality level analysis of potential offer and demand in the zoning choices thus selected, arriving at a discrete number of quality levels.
- ØThe third phase will allow evaluation and comparison of the various ticket pricing hypotheses, taking account of the analysis of potential offer and demand.

The first phase will be to design software architecture allowing each zone in the zoning choice proposed by stakeholders involved in the ticket pricing reform to be examined. The purpose of this first type of examination is to take account first, of the various aspects in order to evaluate the advantages and drawbacks of each zone taken individually. Indicators will be proposed for this, allowing for the items considered to be relevant to this type of analysis, and also for the constraints arising from gaining access to data. Second, to provide an overall evaluation of any zoning choice, using the evaluationsof each zone within it. This overall evaluation will be carried out from various viewpoints, each being formalised by a criterion for comparing zoning choices.

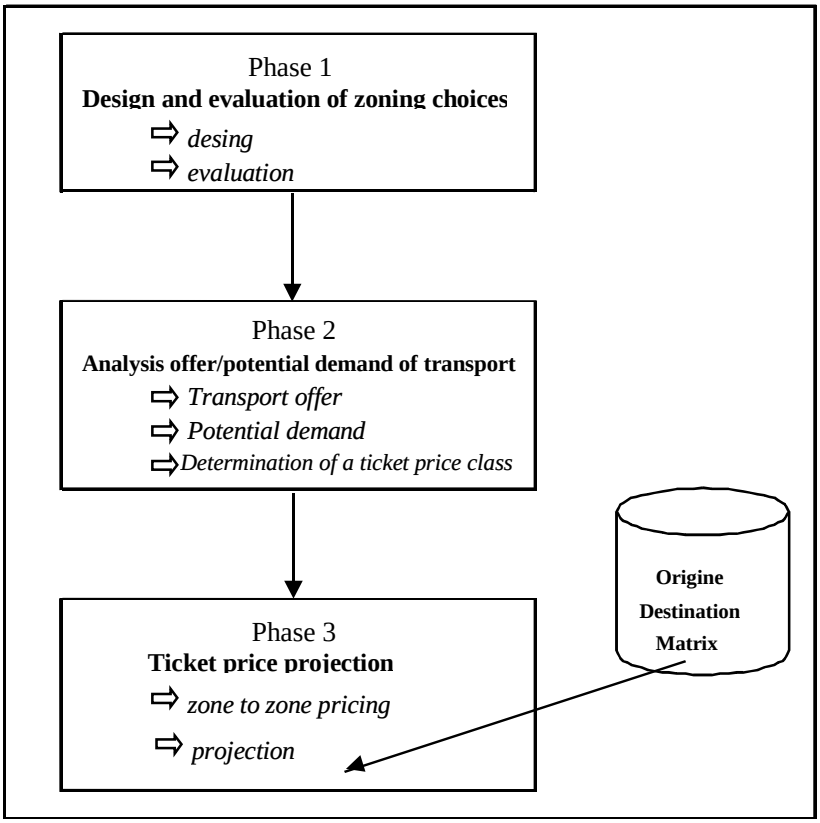


Figure 1 : Structure of the suggested methodology

The second phase will allow analysis of the transport offer and the potential transport demand in each zone in order to reveal their appropriateness or not. This will comprise several stages:

- Ø First, a method of assigning each zone to a transport offer quality level must be devised. This method will be based on a family of criteria which will formalise the characteristics of the transport offer in the zone.
- Ø Second, a method of assigning each zone to a potential demand quality level must be devised. Here, the method will be based on a family of criteria formalising the generators of travel in the zone.
- Ø Third, analysis must be made of the quality level of the transport offer and demand using these two methods, for each zone of any zoning choice made during the first phase. This double analysis will allow the adequacy of the transport offer to the potential demand to be

evaluated. This adequacy will then serve in assigning ticket pricing classes to the various zones in a zoning choice.

The third phase will provide the means for evaluating and comparing various ticket pricing strategies for a given zoning choice. Origine Destination Matrices (ODMs) will allow simulation of the impact of these pricing strategies. This phase will be divided into two stages :

- the first stage will define ticket pricing matrices for each zone,
- the second stage will make financial projections by applying a ticket price matrix to an Origine Destination Matrix and thus arrive at an estimated revenue.

The aim of our contribution is to build a conceptual and methodological framework for study into reform of public transport ticket pricing in the Ile de France, and to define the functional specifications of software which will serve as a basis for concertation between the stakeholders involved in identifying a zoning choice satisfactory to all for the purpose of this ticket pricing reform. This tool is to be a means of exchanges and discussion between the various stakeholders. It is not an instrument for automatic problem solving, but a tool which should assist the stakeholders in arriving at "the best possible" zoning choice for each of them, in the context of ticket pricing reform.

2. A Multi-Stakeholder Decision-Making Process

In what follows, the term "stakeholders" will refer to individuals or groups of individuals who, because of their value system, directly or indirectly influence the decision, either at first degree because of their intervention, or at second degree by the manner in which they use the action of other individuals [Roy, Bouyssou 93]. Stakeholders may be parties to the decision who influence it by their own requirements, passive stakeholders who are subjected to the conditions arising from the decision, which is supposed to take account of their preferences, or latent stakeholders who interfere indirectly in the same way as passive ones, although they have no direct stake in the consequences of the decision.

One of the characteristics of the public transport ticket pricing problem in the Ile de France is that ticket pricing reform must be undertaken in concertation with many stakeholders. There are several categories of these:

- The STP, which is the organising authority, in charge of operating public transport networks and line, which must set out the required routes, how they are to be operated, and designate the operator in accordance with the rules of its own founding charter; it must also decide on ticket prices and price structures, approve large investments and implement an active service quality policy in close association with the Region. Finally, it must undertake studies to ascertain travel pattern changes and the needs of Ile de France dwellers or "Franciliens" so that tomorrow's networks can be developed;
- Local authorities (districts, grouped districts, and *départements* (French geographical and administrative entities) which may commission bus lines or networks ;
- The Regional Council, which subsidises transport operators indirectly through local authorities, participates in investment in rolling stock on certain conditions, and also participates in that for facilities and operation of lines to impoverished areas in compliance with the French government's policy for towns ;
- Public transport companies (the RATP and SNCF), which operate road transport for travellers in the Ile de France; the RATP operates public transport lines and networks, and can also operate other networks or lines or build and equip new lines ;
- Private transport companies (80) which operate lines or networks either on their own account or on behalf of sub-contractors, and are divided into two types: those that belong to groups, and those considered as independent;
- The APTR (Association Professionnelle des Transporteurs Routiers, professional transport operators association) for the Paris region, and the ADATRIF (Association pour le Développement et l'Amélioration du Transport en Ile de France, the association for development and improvement of transport in the Ile de France), which are associations of private transport companies operating regular public transport lines, thus making up part of the Ile de France transport system;
- The customers using the transport networks and lines in the Ile de France;
- Social partners.

In our work we needed to make a clear distinction between two types of stakeholder: first, the interested parties represented by the STP, the RATP, the SNCF, the APTR and the ADATRIF (representing the private companies), the local authorities, the elected officials of the départements and regions, and second, the customers and social partners. It should be noted that it was at the STP's request that this study was undertaken. It therefore has a role as the body requesting a concertation method for ticket price reform, as befits its position as the organising body for public transport.

Our approach here will be to include the various stakeholders and foster concertation from the outset, in order to arrive at collectively acceptable results. This means that:

- the social and political context of the decision will be more carefully taken into account,
- the problem will be more thoroughly formulated since all the stakeholders will be involved right from the start,
- the final decision will be closer to a consensus, and therefore sounder and better accepted.

This approach will allow the STP to find a common ground with the various stakeholders in the reform and arrive at a consensus. This is why the tool which will be the basis of methodological implementation must be a means of dialogue between the stakeholders and lead to discussions. It is not merely an instrument for an optimum solution, but a tool to help the stakeholders select the "best zoning choice" according to their own lights, for the ticket pricing reform. Nor will it be an automatic tool, that is, one imposing its solution on the basis of a calculating procedure, but it will be a communication tool, allowing the various stakeholders in ticket pricing reform to discuss the possible scenarios. Finally, the tool will not automatically generate zoning selections, since each stakeholder may submit one or several zoning choices for the Ile de France, and/ or ticket price strategies.

3. First phase : Design and evaluation of zoning choices to divide up the Ile-de-France

3.1 Methodological framework

The first phase will allow the stakeholders in the decision process to invent different zoning possibilities for the Ile de France and compare them. It is important to note that in this first phase, zoning is undertaken without taking account of the ticket price bases which they will support. The methodological framework we suggest will include a number of concepts that we will introduce progressively.

It should be mentioned here that the term "zoning choice" refers to the various ways of dividing the Ile de France into zones. More precisely, the territory is divided into zones, each of which constitute a group of districts (communes), or even "parts of districts". The only parts of districts that will be taken into consideration are those which appear in today's carte orange season ticket. These parts of districts and those districts that cannot be divided up will be called atoms. A zone is therefore completely defined by the list of atoms it comprises.

The methodology of this initial phase will comprise the following analysis levels:

- One to assist stakeholders in inventing zoning choices, with analysis of each zone of the zoning choice. It supplies the results needed for an initial examination based on the various relevant aspects, leading to evaluation of the advantages and drawbacks of each individual zone. Indicators have been designed for this purpose, taking account both of the aspects deemed relevant by the stakeholders for this level of analysis, and the constraints of data accessibility.
- The second to furnish the materials for a comparison of the zoning solutions. It will be based on the evaluation of each zone in the zoning choice order to make an overall evaluation of the zoning choice according to various criteria. For each zone, a criterion is created to allow a second type of examination, this time of the entire zoning choice.

The two levels of analysis will be implemented as follows:

First level of analysis: zoning design assistance

This is to allow analysis of each zone of a proposed zoning choice in order to detect drawbacks and advantages, and suggest possible remodelling. Indicators will be introduced to point up intrinsic defects and qualities in the zone. Their values will indicate the acceptability of a zone within a zoning choice as compared to the aspect assigned to each indicator. These indicators were built following the work of Stathopoulos (Stathopoulos 86 and 97), and their

detailed definition can be found in Appendix 1. Paragraph 3.2. below gives a brief outline of the indicators. According to the aspect assigned to it, each indicator distinguishes:

- zones with large defects needing remodelling,
- zones with minor defects for which remodelling is not essential,
- zones with no defects and requiring no remodelling.

Remodelling, in this context, means a reconfiguration at the margin of the zone, which will attenuate the defects. It should be noted that remodelling which improves the zone examined in the light of one indicator may lead to deterioration of the zone in the light of other indicators. Use of these indicators allows the zoning inventor to arrive at "efficient" zoning through successive changes and remodelling, that is to say, at solutions which cannot be improved without spoiling other aspects.

Second level of analysis : comparison of zoning choices previously determined

The purpose of this second level of analysis is to provide the information needed to compare any two zoning choices according to different viewpoints. The instrument of comparison is the criterion. Each criterion corresponds to a viewpoint deemed relevant by the stakeholders (for definition of these indicators, see Appendix 2).

A criterion therefore serves as a synthetic indicator of a zoning choice as a whole, so that it can be ranked on a scale for the viewpoint in question (Roy 85). The scale may, depending on the case, be

- defined using a concrete quantity based on a physical origin and unit, such as the number of kilometres or number of intermediary stations;
- built using an agreed unit such as the number of penalty points for each type of defect, in the light of the viewpoint in question,
- created using an abstract notation.

The constituents of the scale are rankings; the criterion therefore assigns a single ranking to each zoning choice for the viewpoint in question. This ranking is what could be called the evaluation of the zoning choice as measured by the criterion. The comparison of two zoning choices for one viewpoint is thus reduced to two rankings showing the of those zoning choices on the corresponding criterion. It is therefore essential that the order of rankings clearly reflect rising or falling preferences. Although each ranking is characterised by a number to make comparison easier, it is important to bear in mind that this number is a merely ordinal representation and cannot be used significantly in arithmetical additions or products

The evaluation of a zoning choice against a criterion is determined using the value of certain indicators for the zones within a zoning choice (Appendix 2). These indicators then become the basis for the criterion. The way the various values of the indicators for each zone of a zoning choice are combined to define the evaluation of the zoning choice must therefore be specified.

The aggregation thus produced may, in some cases, be the result of a simple addition; in other cases, the compensatory nature of this method may prove to be ill-adapted. In extreme cases, a viewpoint could be imagined whereby a zoning choice is ranked for the zone where it has the worst ranking under that viewpoint. The aggregate procedure known as Ordered Weighted Average (Yager 88) offers a range of intermediate aggregating formulae that can be adapted to the viewpoint selected by the stakeholders.

3.2 Indicators identifying the advantages and drawbacks of a zone

These indicators were defined to highlight the acceptability of a zone in a zoning choice and validated by the stakeholders in the ticket pricing reform process. They are grouped according to the type of concern they refer to:

Ø Indicators for the location of the zone in relation to the network

- Number of stations in rail network,
- Number of buses on route service,
- Density of internal offer,
- Density of the external offer on the rail network,
- Density of bus external offer,
- Location of stations in rail network.

Ø Indicators of mobility structure in a zone

- Access to the rail network,
- Commuting,
- Presence of public services.

Ø Indicators that the zone corresponds to administrative structures

- *Département* boundaries respected,
- Urban community boundaries respected.

Ø Indicators of centres of attraction in the zone

- Location of shopping malls,
- Location of healthcare centres.

3.3 Criteria for comparing zoning choices

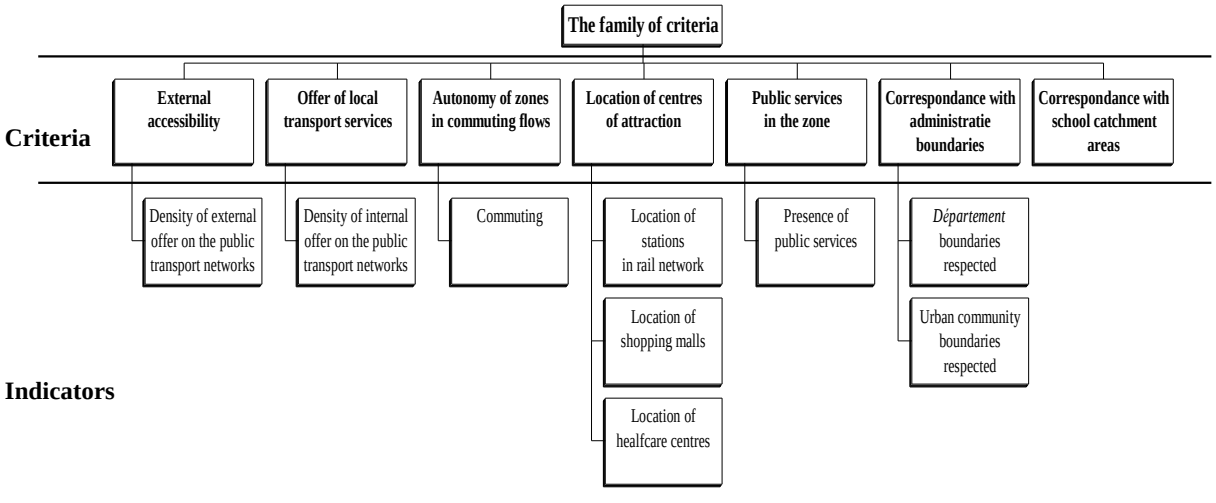
The need to create criteria for comparing zones is due chiefly to the fact that several zoning choices may be made by various stakeholders. Stakeholders must therefore be able to compare their choices of zoning using criteria which have been accepted by consensus as a basis for comparison. The criteria presented below were chosen by all and were deemed suitable for this task.

Each criterion allows a zoning choice to be evaluated as a whole in the light of a given viewpoint. The criterion is an instrument for comparing zoning choices, other things being equal. No one criterion should be taken in isolation but as a constituent part of the criteria family. Criteria are constructed so that a zoning choice is all the better as its evaluation is better ranked, all other things being equal (in other words, equal evaluation for the other criteria).

For most of the criteria, zoning evaluation is based on the value of the zones in the zoning choice for certain indicators. The purpose of some of these criteria is to take account of a particular type of defect in some zones in the zoning choice, on the basis of the indicators supporting them. Evaluation of a zoning choice for one criterion is therefore based on several values, and so it is necessary to use an aggregation operator which will synthesise the value of the zones for the indicators using the zoning choice evaluation for the criteria. For the reasons indicated earlier (3.1.), it is the ordered weighted average (OWA) which was chosen as a basis for this aggregation.

The criteria were designed to be applicable to zoning choices with differing numbers of zones. Finally, it is important to realise that the discriminatory capacity of the criteria thus designed is not absolute, due to the inaccuracy of the data they are based on (Roy 89). In order not to place more significance on the data than is advisable, discrimination thresholds will be introduced later.

The family of criteria is as follows: - External accessibility,
- Offer of local transport services,
- Autonomy of zones in commuting flows,
- Location of centres of attraction,
- Public services in the zone,
- Correspondence with administrative boundaries,
- Correspondence with school catchment areas.



4. Second phase : Analysis of offer and potential demand in the Ile de France for the purpose of new ticket pricing

Transport offer and the potential demand in a given zone are two basic requirements when fixing a transport pricing system in such a zone. Detailed analysis of each zone of a zoning choice is therefore necessary in order to develop a ticket pricing strategy. This analysis can be applied for each zone selected in the first phase. The second phase can be divided into three stages:

Analysis of offer: Determination of the transport offer in each zone. For each zone, this offer will be ranked in order of quality, based on the set of criteria deemed relevant and validated by the various stakeholders in the reform (cf. Appendix 3).

Analysis of demand: Determination of the potential demand in each zone. For each zone, potential demand will be ranked in order of quality, based on the main generators of travel in the zone. These travel generators are indirect measurements of the potential demand, and have been validated by the various stakeholders in the reform (cf. Appendix 3).

Determination of a ticket pricing class for each zone in a zoning choice: A ticket pricing class corresponds to all the zones with the same transport offer and potential demand characteristics. All zones in the same ticket pricing class will be treated the same in designing ticket pricing strategy. Furthermore, this third stage will allow the adequacy of the transport offer to potential demand in each zone to be evaluated.

4.1 Analysis of the offer

This first stage consists of assigning zones to categories corresponding to the quality level of the offer. Therefore a model must be built to determine the quality of the transport offer in each zone depending on its characteristics.

Defining the scale of quality to measure the transport offer in a zone.

This scale comprises ordered categories, describing the various levels of transport offer in rising order; each category therefore represents a quality ranking of the offer. The categories are designed based on the idea that the zones assigned to the same category of offer will be treated the same as regards ticket pricing. Categories are designed to correspond to the following:

Very high offer, category : $\mathbf{O_4}$
Fairly high offer, category : $\mathbf{O_3}$
Fairly low offer, category : $\mathbf{O_2}$
Very low offer, category : $\mathbf{O_1}$

To pinpoint the semantic content of a very high, fairly high, fairly low and very low offer, criteria were laid down by the STP in concertation with the various stakeholders in the ticket pricing reform. The criteria selected are as follows (implementation of which is described in Appendix 3):

- density of the rail network,
- estimated density of the bus network,
- quantity of the internal offer in the rail network
- quantity of external offer,
- direct accessibility (0 - 500 metres) to public transport networks,
- motorised accessibility (0 - 5 km) to the rail network,
- variety of offer,
- frequency of rail network inside zones,
- frequency of bus network inside zones,
- frequency of rail network between zones,
- frequency of bus network between zones.

Assignment of zones by the ELECTRE TRI method

The purpose of the above criteria is to set up a model allowing the transport offer in a zone to be evaluated on the scale of quality introduced above. This is done using the multi-criteria assigning method called ELECTRE TRI. We therefore formulate the problem in terms of sorting, in order to assign each zone to a suitable category, examining its evaluation on the criteria.

In the ELECTRE TRI method, the categories are characterised by profiles (noted b_h), identifying the limit between two successive categories, as shown in Figure 2:

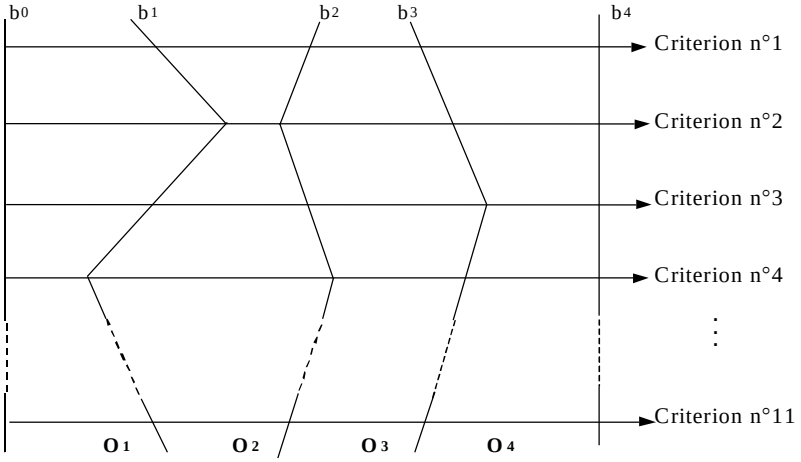


Figure 2 : Definition of categories by limit profiles

The assignment of a zone to a category is based on comparison of the zone with b_h, profiles (category boundaries). Comparison of zones with profiles is based on the zone evaluations and profiles for the various criteria, and additional information on the importance of each criteria and its discrimination power. Use of the ELECTRE TRI method therefore requires determination of

- category boundaries defined by limit profiles b_h,
- the relative importance of the various criteria, specified by importance coefficients k_j and veto thresholds v_j,
- the discriminating power of each criterion, defined by indifference thresholds q_j and preference thresholds p_j [Roy, Vincke 84].

However, stakeholders do not always have a clear idea of the value to give to these parameters. It is difficult for them accurately to analyse the role played by each parameter in the assignment. This is why it is unrealistic to try to calibrate a model like this by questioning stakeholders directly on parameter values. Furthermore, this tool is designed to facilitate concertation between the various stakeholders in the ticket pricing reform and it is illusory to try to organise communication on the basis of the parameter values.

In order to calibrate the model and fix values for the model parameters, we suggest that reference be made to a set of zones typical of each level of offer. These example zones will serve as standards in defining rules for allocating them to a categorie and therefore will allow parameter values for the ELECTRE TRI model to be fixed any zone.

Consequently, to calibrate the model, the stakeholders must determine a certain number of imaginary or real zones, the evaluations of which they will indicate for each criterion, and arrive at an agreement on the offer category. Additional information on the value of certain parameters may also be introduced. Using this information, calibration of the ELECTRE TRI model will consist of determining the value of all the parameters so that the method assigns the example zones to the offer categories in conformity with the stakeholders' wishes (for more details on the ELECTRE TRI techniques of parameter inference, see [Yu 92], [Roy, Bouyssou 93], [Mousseau *et al*. 99, a, b]).

The zones used as standards for calibration of the ELECTRE TRI model must have profiles as varied as possible in relation to the offer and demand criteria, and cover all the rankings of offer and demand quality level. They must be evaluated and agreed by all stakeholders in order to serve as a common reference.

If irreconcilable differences emerge, they must be identified by sets of distinct standard zones. Finally, standard zones must not correspond to the zones of a zoning choice, so that local political influence in the ticket pricing reform question will not interfere with the analysis of offer and demand

4.2 Analysis of demand

The second stage determines a quality ranking for potential demand in each zone of a zoning choice. Potential demand associated with a zone relates to the demand expressed on journeys departing from or arriving in the zone in question. It is not a question of counting up past demand, nor of forecasting future demand, but only of basing this quality ranking on the greater or lesser importance of transport generators in the zone. Although public transport customers make their choices based on transport ticket pricing, this will not be taken into account in this stage. The level of

potential demand here refers mainly to the foreseeable volume of journeys given the territorial structure of the zone.

This second stage therefore consists of assigning zones to categories corresponding to the quality ranking of the demand. A model must be built to determine the quality ranking of the potential demand in each zone according to the demand generators in this zone.

The overall structure of this stage is similar to that for offer analysis; it is based on the identification of criteria which take account of the nature and importance of travel generators. Then the ELECTRE TRI model is used to assign each zone to a category of demand on the basis of these criteria. The criteria are used in this ELECTRE TRI model which assigns each zone to a quality ranking of potential demand.

Definition the scale of the quality ranking to evaluate potential demand in a zone

This scale is composed of ordered categories ranking the various levels of potential demand in rising or descending order. Each category therefore represents a potential demand quality ranking. Conception of categories is based on the fact that the zones assigned to the same category of potential demand are treated the same as regards ticket pricing. Categories are designed to correspond to the following

Very high potential demand, category : $\mathbf{Pd_4}$
Fairly high potential demand, category : $\mathbf{Pd_3}$
Fairly low potential demand, category : $\mathbf{Pd_2}$
Very low potential demand, category : $\mathbf{Pd_1}$

To detail the semantic content of a very high, fairly high, fairly low and very low offer, criteria were laid down by the STP in concertation with the various stakeholders in the ticket pricing reform.

Definition of criteria for potential demand is based on the main reasons for travel defined by Enquête Globale et Transport (EGT, General surveys and transport, 1990) which enables a zone to be qualified according to the level of expectation of the population living there. EGT 90 gives a description of Ile de France dwellers' travel patterns (15,980 households interviewed at home) within the Ile de France on an ordinary weekday. The main reasons for travel revealed by this survey were:

Reason for travelling	% of journeys
Home	39.2 %
Personal business, health, visits, administrative	18.1 %
Work	14.2 %
Shopping	9.4 %
School	7.9 %
Leisure	6.1 %
Professional business	5.1 %

The family of criteria for evaluation of potential demand in a zone was built up based on the following idea: for each reason for travelling, a "travel generator" was associated, in other words an explanatory variable deemed relevant in measuring the volume of demand for this type of travel. For instance, the indirect measurement of the intensity of demand associated with the zone for the "home" reason is based on the explanatory variable "population in the zone". The following explanatory variables were adopted:

- population for the "home" reason,
- job for the "work and professional business" reasons,
- shopping surfaces for the "shopping" reason,
- number of *Lycées* and school places for the "school" reason,
- number of doctors and hospital beds for the "personal business" reason,
- number of cinemas, sports facilities and theatres for the "leisure" reason.

Given the availability of data on the explanatory variables, the criteria chosen for evaluating potential demand are as follows (their operational definition can be found in Appendix 3). These criteria were validated by the various stakeholders in the reform:

- home
- work and professional business,
- shopping
- school
- personal business
- leisure.

4.3 Determination of a ticket price class for each zone in a zoning choice

The third stage in the second phase is to combine the analyses of offer and potential demand previously made. The results may be presented in the form of a table in which transport offer levels (0_4 , 0_3 0_2, 0_1), and potential demand levels (Dp_4, Dp_3, Dp_2, Dp_1) are set forth respectively in lines and columns. Analysis of offer and potential demand therefore enables each zone to be placed in one of the sixteen categories of the following table.

	Pd_4	Pd_3	Pd_2	Pd_1
O_4				
O_3				
O_2				
O_1				

	Offer > Demand
	Demand > Offer

The offer and potential demand categories in each zone are a constituent element of ticket pricing strategy. This information is taken into account in pricing from one zone to another, so that two zones with the same offer and demand levels will have the same ticket prices.

Moreover, this table will allow evaluation of the adequacy of offer to demand in each zone. The diagonal will represent the "normal" state, that is, that where potential demand in the zone corresponds to offer. Above the diagonal, offer level is higher than potential demand, which means that the transport offer is too great for the few people needing transport. Below the diagonal, potential demand is higher than the offer, and there is strong demand compared to available services. The transport offer here is not adapted to customer needs.

5. Third phase : Ticket price projections

5.1 Overall design

The third phase will use the analysis of offer and potential demand in each zone of zoning choices to design ticket pricing systems for each zone, and deduce financial projections therefrom, on the basis of Origine Destination Matrix (ODM) hypotheses. More precisely, this phase will be divided into the following two stages:

- The first stage will be to define ticket pricing matrices for a given zone, specifying the cost of travel from one zone to another. These matrices may be defined by the stakeholders in the study or built up using a ticket pricing rule for which parameters can be set.
- The second stage will be to apply these ticket pricing matrices to ODMs. The result of this analysis will be a financial projection produced by applying a ticket pricing rule to a given zoning choice on the basis of an ODM .

Before entering into details as to how to implement this phase, the nature and finality of the financial projections envisaged must be clarified. First of all, the main aim of this phase is to arrive at estimated financial projections for each zoning choice and ticket pricing rule, using an ODM. However, it is essential to put the absolute value of the sums thus calculated in perspective. This is because the results are based on partially inaccurate information (Roy 89), more particularly because:

- The ODMs used are only hypotheses of traffic evolution. Added to this, the division of the Ile de France in these matrices does not necessarily correspond to the zoning choices which may be proposed in this study (especially in the outer suburbs),
- The information needed for analysis of transport offer and potential demand is based on past data which may change.

The above remarks illustrate the fact that the volumes calculated must be used for purposes of comparison and not in absolute terms.

5.2 Construction of ticket pricing matrices

The purpose of building ticket pricing matrices for each zone is to assist in calculating financial projections. The matrices may be defined directly by the stakeholders by specifying the prices of n^2 journeys where there are n zones. However, this is a complicated process and does not always allow definition of the rules underlying ticket pricing. It will therefore be relevant to define the ticket pricing rules which are processes of building up ticket pricing matrices based on the same principles and with common characteristics.

5.2.1 Structure of ticket pricing rules

We have adopted an approach based on definition of ticket pricing from one zone to another. This hypothesis has the following consequences:

- the cost of a journey depends on the transport offer level, and on potential demand in the entry and exit zones on the network for that journey,
- the ticket pricing rules considered do not distinguish between journeys departing from or arriving in two points of the network within the same zone,
- two journeys departing from entry points in two zones with the same transport offer and potential demand characteristics will be examined in the same way as regards ticket pricing. This is also the case for exit points on the network.

The characteristics of the entry and exit zone, in terms of offer and potential demand, are relevant variables in constituting a ticket pricing matrix. Among relevant variables, the following are worthy of note:

- characteristics of entry and exit zones,
- distance (estimated from one zone barycentre to another),
- transport mode
- the time at which the journey was made.

However, the last two variables cannot be retained due to the fact that they cannot be taken into account in the projection (ODMs specify neither times nor modes of travel) and because they give rise to ambiguity when taken into account for ticket pricing rules (particularly as regards travel mode). The ticket pricing rules envisaged are therefore based on the entry *(e)* and exit *(x)* zones on the network, and on journey distance *(d) (price = f(e, x, d)).*

5.2.2 Proposal of a ticket pricing rule

It seems reasonable to apply to function f the following properties:

- *f(e,x,d) = f(x,e,d),* the price of outward and inward journeys being identical,
- the price increases with distance : $\frac{\partial f}{\partial d} > 0$

The ticket pricing rule distinguishes between journeys within a zone (for which $e=x$) and journeys between zones (for which ($e \neq x$).

Journeys within zones

The ticket pricing rule for journeys within a zone disregards distance and depends only on the offer and potential demand in the zone considered. Ticket pricing within a zone is therefore defined by a table showing prices as a function of offer and potential demand levels.

Journeys between zones:

Ticket pricing for journeys between zones may be structured as follows:

$$price = tax(e) + tax(x) + pdc(d)$$

- *tax(e)* and *tax(x)* are two accessibility taxes, for entrance and exit to the network.

These accessibility taxes are calculated in the same way and are based on the level of offer and potential demand in the zone in question. They are defined by the datum of the table which specifies the value of the accessibility tax as a function of the level of offer and potential demand in the zone in question.

- *pdc(d)* is the price of the distance covered, defined by a price per kilometre p_k. *(pdc(d)=p_k * d).*

Another type of ticket pricing system for journeys between zones can be designed, based on a multiplying form. In this case, the price for distance covered could be modulated by two multiplying factors linked to offer and potential demand levels in the entrance and exit zones.

6. Implementation of the methodology in the TARIF software.

6.1 Overall presentation

The methodology described in the previous sections has been implemented in software called TARIF. The TARIF software has been developed through a partnership involving the *Syndicat des Transports Parisiens* (end user), the LAMSADE laboratory (methodology supervisor) and Khi2 (software company). The Geographical Information System (GIS) underlying every geographical manipulation id ARCVIEW (ESRI) and the computations are programmed in C.

This software integrates all data required by the three phases of the methodology. This data is available through a geographical and alphanumeric display. Each piece of information contained in the database is subject to evolution over time; therefore, it is possible to update the data in the TARIF software.

Two level of use are defined,

1. a *standard user's level* which corresponds to basic functionalities dealing with the definition/manipulation of zoning choices and pricing strategies,
2. an *administrator's level* which integrates all standard user's functionalities together with other ones that deals with the software configuration and data importation

6.2 Presentation of the main functionalities

We will describe in this section the main options available by a standard user in the TARIF software. These options correspond to the operations required by the three phases of the methodology. At each phase, the TARIF software is designed so that the user can perform *what-if* analyses. We will not consider here the administrators functionnalities which correspond to rather standard features of any software.

6.2.1. First phase: Design and evaluation of zoning choices

The TARIF software manages zoning choices stored in files organised in folders. The user begins a working session with a map of the Paris region representing the atoms. He/she is to group a selection of connected atoms in order to define a zone. These zones can be defined either "manually" one by one or through a pattern-based generation. This second option makes it possible to generate a zoning choice as close as possible to a pattern (triangle, rectangle or hexagon). A zoning choice is completely defined as soon as each atom is assigned to a zone (cf. Figure 3).

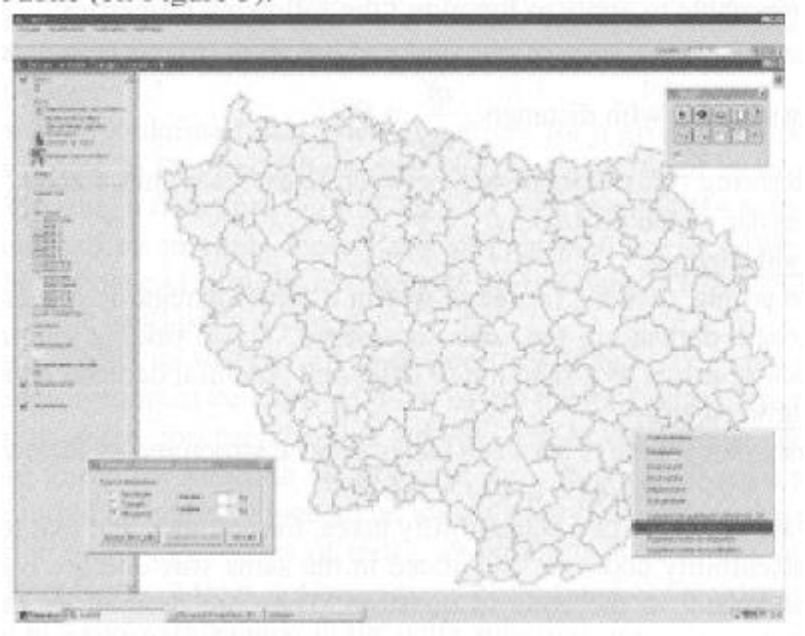


Figure 3 : A zoning Choice

Once the current zoning choice is completely defined, it is possible to compute the indicators (cf. §3.2).On the basis of user's defined thresholds, these indicators distinguishes among zones with large defects needing remodelling, zones with minor defects for which remodelling is not essential and zones with no defects and requiring no remodelling.

Information concerning the indicators' values is available through a tabular and/or geographical display. In order to analyse the indicators' values, the user can zoom on the map in order to access to different levels of details concerning the indicators computations. On the basis of this information, the user may decide to remodel some zones that perform badly on indicators so as to improve the performance of these zones. Using these functionnalities, the user can enter into an iterative trial/error process that stops when he/she is satisfied with the current zoning choice. At this stage, the criteria values can be computed (cf. §3.3).

6.2.2. Second phase: Analysis of offer and potential demand

The functionnalities of the second phase mainly correspond to computations and visualization of the results.The offer and potential demand criteria can be computed for each zone of the current zoning choice. The assignments of each zone to a category of offer (cf §4.1) and potential demand (cf §4.2) are then computed using the ELECTRE TRI assignment rules (cf. Figure 4).

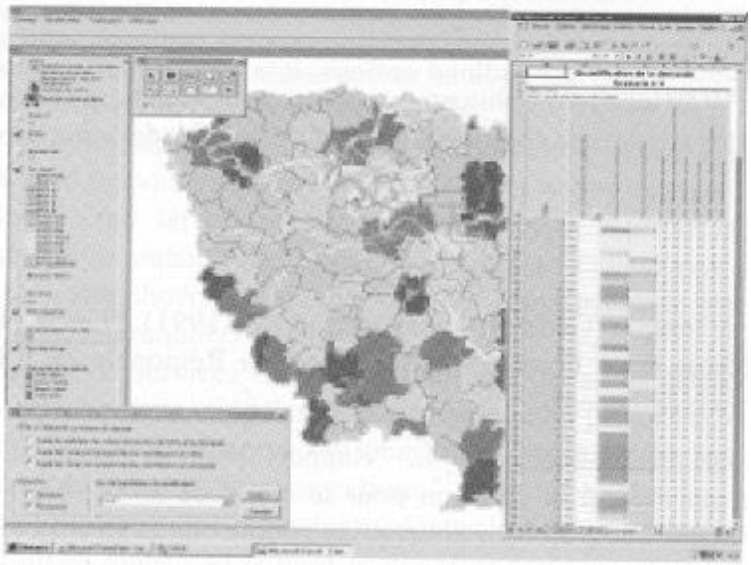


Figure 4 : Visual and tabular analysis of the offer

6.2.3. Third phase: Ticket price projections

Through this phase, the user should either specify a ticket pricing rule (cf. §5.2.1) from which a zone to zone ticket pricing matrixis computed, or directly specify a ticket pricing matrix. The user should then select an Origin/Destination matrix on the basis of which a financial projection can be computed.

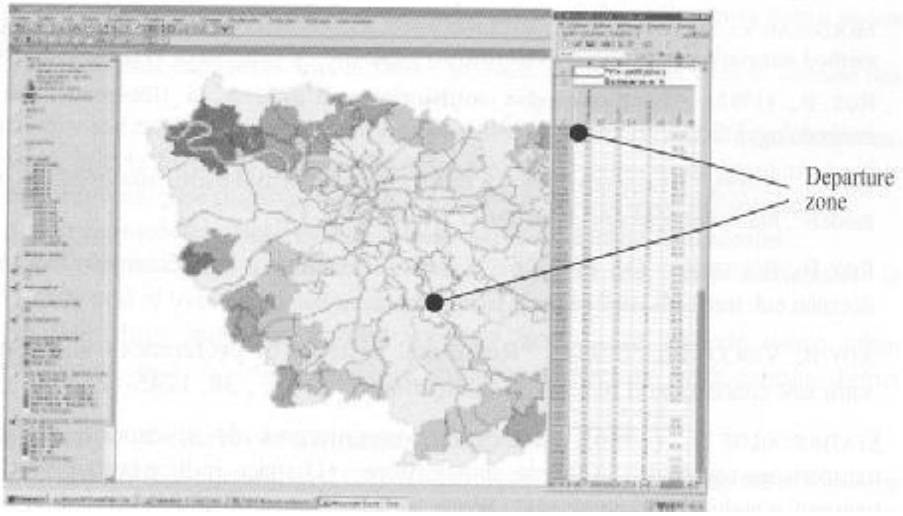


Figure 5 : Visual and tabular prices from a departure zone

Conclusion

Our contribution has been to propose a conceptual and methodological framework to the STP for the purpose of examining ticket pricing reform in public transport in the Ile de France. This framework has led to the design of software. This tool allows the relevance of new proposals for dividing the Ile de France into new geographical and ticket pricing zones to be validated. In other words, it makes it possible to input, assess, modify and compare zoning choices, and carry out pricing projections based on analysis of offer and demand. This software constitutes the decision aiding tool offered to stakeholders in the ticket pricing reform with which to design new ticket pricing strategies.

The role of this decision aiding tool is to promote concertation between stakeholders rather than offer solutions resulting from automated problem solving. Its purpose is therefore to reconcile the arguments of the stakeholders in order to arrive at a collectively agreed reform which has been decided transparently. In this regard it should be remembered that the various actors have been included in the methodology-defining process (particularly as regards definition of indicators and criteria). The tool is therefore the result of a joint construction and its method of production has fostered acceptance of the methodology by its users and allowed discussion of the possible design possibilities.

The tool is designed to promote a decision process fostering the emergence of new solutions in the course of its use. The recommended type of decision process contrasts with standard ones which analyse and compare a limited number of pre-defined options. It is clear that the nature of this decision process is largely influenced by the underlying philosophy of its method. The paradigm chosen in this work will allow the stakeholders to build new solutions together during the decision process.

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APPENDIX 1 : Indicators identifying advantages and drawbacks of a zone

These indicators have been defined to point up the acceptability of a zone in a zoning choice and have been validated by the stakeholders in the ticket pricing reform. The indicators are grouped into types of concern referred to (for more details on the method of calculating these indicators and criteria, see [Mousseau, Roy and Sommerlatt 96 and 98] :

Ø Indicators of zone location in relation to the transport network

a) Number of stations in the rail network: this indicator evaluates the quality of rail services and is used to harmonise distribution of stations in each zone.

b) Number of bus services: this indicator serves to evaluate bus service quality and is used to harmonise distribution of bus services in each zone.

c) Density of internal offer: this indicator evaluates the number of local public transport services in a zone and is used to evaluate the travel possibilities within that zone.

d) Density of external rail service offer : this indicator takes account of the number of rail services to destinations outside the zone and is used to evaluate travel possibilities outside that zone. The indicator shows the number of other zones accessible from inside the zone, via rail services without interconnections.

e) Density of external bus services offer: this indicator shows the quantity of bus services to destinations outside the zone and is used to evaluate travel possibilities outside that zone. The evaluation of the indicator concerns the number of other zones accessible from inside the zone, via bus services without interconnections.

f) Location of railway stations: this indicator evaluates location of stations in a zone in relation to the border with other zones and is used to avoid undesirable repercussions on neighbouring zones. The indicator evaluation measured is distance between the station and the border. Where there are several stations, the smallest distance is used.

ØIndicators of mobility structure within a zone

g) Access to the rail network: this indicator shows if the population moves towards a station on the rail network within the zone, and is used to encourage movement within the subdivision. There are two indicators measuring access to the rail network: population living less than 500 metres from a station within the zone and that living over five kilometres from a station within the zone.

h) Commuting: this indicator measures travel flows in each zone and is used to increase this type of travel in the zone.

i) Public services: this indicator shows the number of public services (post offices, cemeteries, secondary schools, sports facilities etc) in a zone to avoid the population going into another zone to use these services. The purpose is to harmonise public services between zones.

Ø Indicators showing correspondence between administrative and zone boundaries

j) *Département* boundaries: this indicator shows whether the zone corresponds to administrative limits and is used to avoid territorial problems.

k) Urban communities: this indicator shows whether zones are entirely within urban community boundaries and is used to avoid creating difficulty with existing district groupings.

Ø Indicators showing location of centres of attraction

l) Location of shopping malls: this indicator reveals the location of shopping malls with over 5,000 m^2 surface in the zone. the purpose is to avoid undesirable repercussions on neighbouring zones.

m) Location of healthcare centres: this indicator reveals the location of healthcare centres such as hospitals and clinics in the zone. the purpose is to avoid undesirable repercussions on neighbouring zones..

APPENDIX 2 : Criteria for comparing zoning choices

There are seven criteria in this family:

Criterion n°1 : External accessibility
This criterion measures the opportunities for the population of a zone to travel outside this zone. For each zone, the number of other zones accessible via public transport without interconnections is counted over the number of accessible zones. The zoning choice is evaluated for this criterion by ordered weighted averaging (OWA) of the external offer of public transport networks in each zone of the zoning choice. In this OWA, the worst zones are over-weighted.

Criterion n°2 : Offer of local transport services
This criterion is used to evaluate travel opportunities for the population within a zone. It is evaluated at zone level by the total number of different possible journeys (without interconnection, for all lines having at least two stops within the zone), divided by the average surface. The evaluation of the zoning choice for this criterion is determined by ordered weighted averaging of the possible journeys in all its zones. In this OWA, the worst zones are over-weighted.

Criterion n°3 : Autonomy of zones in commuting flows
This criterion measures the proportion of the working population commuting within the zones of a zoning choice. It is evaluated at zone level by the percentage of working population remaining within the zone. Evaluation of the zoning choice for this criterion is determined by the proportion of zones in the zoning choice of which at least 25% of the working population remain within a zone for commuting purposes.

Criterion n°4 : Location of centres of attraction
This criterion measures the locating of stations, healthcare centres and shopping malls in each zone of the zoning choice. It takes account of the location of centres of attraction in each zone of the zoning choice. It is evaluated for each zone by:

- 10 : if no centre of attraction is located within one kilometre of its borders;
- (10-X-1/2Y-1/2Z) : if there are X stations, Y healthcare centres and Z shopping malls within one kilometre of its borders;
- 0 : si X-1/2Y-1/2Z > 10.

A station near to the border is deemed twice as much a disadvantage as a healthcare centre or shopping mall. The zoning choice is evaluated on this criterion by averaging the centres of attraction located less than one kilometre from zone borders.

Criterion n°5 : Public services in the zone
This criterion measures the number of public services such as secondary schools, cemeteries, post offices and sports facilities in each zone of the zoning choice. The number of types of public service in each zone is taken into account. The zoning choice is evaluated on this criterion via an ordered weighted average of the number of types of public service in a zone. In this OWA, the worst zones in the zoning choice are overweighted.

Criterion n°6 : Correspondence with administrative boundaries
This criterion measures the zones of a zoning choice which do not correspond to département boundaries or urban community limits. Each zone is evaluated for both types of limit. The zoning choice is evaluated on this criterion via an ordered weighted average of the zones. In this OWA, the best zones of the zoning choice are overweighted.

Criterion n°7 : Correspondence with school catchment areas
This criterion measures the zoning choice for correspondence with school catchment areas. A zoning choice is all the better as the borders of its zones intersect school catchment areas less. This criterion may be duplicated in each case where adequacy with another division of the Ile de France into sections is required (for season tickets, urban communities etc.)

APPENDIX 3 : Criteria for transport offer and potential demand in a zone

Analysis of the offer

Offer criterion n°1 : Density of rail network
This criterion measures the quality of the rail network offer in the zone, evaluating possibilities of access to the rail network for the population. It is determined by the number of stations (with or without interconnections) in the zone in relation to the zone surface.

Offer criterion n°2 : Estimated density of bus network
This criterion measures the quality of the bus offer in the zone, evaluating possibilities of access to the bus network for the population. It is determined by the number of bus stops in the zone in relation to the zone surface.

Offer criterion n°3 : Quantity of internal offer of rail network
This criterion measures the number of journeys made by the population within the zone, It is determined by the number of possible different journeys without interconnections but with at least two stops in the zone, in relation to the zone surface.

Offer criterion n°4 : Quantity of external offer
This criterion measures the possibilities for the population to travel to destinations outside the zone. It is determined by the estimated number of bus stops plus the number of rail stations outside the zone in relation to the zone surface.

Offer criterion n°5 : Direct accessibility [0-500m] to public transport networks
This criterion measures the attractiveness of stations in the zone in order to evaluate the population with direct access to a station. It is determined by the proportion of the population located at less than 500 m from a station in relation to the zone population as a whole.

Offer criterion n°6 : Motorised accessibility of rail network [0km-5km]
This criterion measures the ability of the population to reach a station on the rail network, possibly by motorised means. . It is determined by the proportion of the population located under 5 km from a station in the zone in relation to the zone population as a whole.

Offer criterion n°7 : Offer variety
This criterion measures the variety of public transport means (train, RER, metro, tram and bus) in the zone. It is determined by the number of types of transport means in the zone.

Offer criterion n°8 : Rail frequency inside zones
This criterion measures the frequency of trains on the rail network in the zone allowing travel within the zone. It is determined by the number of journeys made on the lines within the zone during the morning rush hour in winter (7.30 - 9.30 am).

Offer criterion n°9 : Bus frequency inside zones
This criterion measures the frequency of buses on the bus network in the zone allowing travel within the zone. It is determined by the number of journeys made on the lines within the zone during the morning rush hour in winter (7.30 - 9.30 am).

Offer criterion n°10 : Rail frequency between zones
This criterion measures the frequency of trains on the rail network in the zone allowing travel to points outside the zone. It is determined by the number of journeys made to points outside the zone during the morning rush hour in winter (7.30 - 9.30 am).

Offer criterion n°11 : Bus frequency between zones
This criterion measures the frequency of buses on the bus network in the zone allowing travel to points outside the zone. It is determined by the number of journeys made to points outside the zone during the morning rush hour in winter (7.30 - 9.30 am).

Analysis of potential demand

Demand criterion n°1 : generator "home ”
This criterion measures population density in the zone to give information on the population likely to live there. The explanatory variable supplying the generator "home" is population. It is determined by zone population relative to zone surface.

Demand criterion n°2 : generators “ work and professional business ”
This criterion measures job opportunities in the zone to give information on its attraction as a working centre. The explanatory variable supplying the generator "work and professional business" is employment. It is determined by the number of jobs in the zone relative to zone surface.

Demand criterion n°3 : generator "shopping ”
This criterion measures the proportion of shopping surfaces in the zone to give information on its attraction to shoppers. The explanatory variable supplying the generator "shopping" is shopping surfaces (>5,000m^2). It is determined by the proportion of zone shopping surfaces relative to zone surface.

Demand criterion n°4 : generator “ school”
This criterion measures the number of schools in the zone. The explanatory variable supplying the generator "school" is the number of secondary schools and number of secondary school places. It is determined by the number of places in collèges and lycées in the zone relative to zone surface.
Demand criterion n°5 : generator “ personal business ”
This criterion measures the attractiveness of the zone for solving personal business. The explanatory variable supplying the generator "personal business" is the number of hospital beds. It is determined by the number of hospital beds in the zone relative to zone surface.

Demand criterion n°6 : generator “ leisure”
This criterion measures leisure facilities in the zone. The explanatory variable supplying the generator "leisure" is the number of cinemas, sports centres and theatres. It is determined by the number of cinemas, sports centres and theatres in the zone relative to zone surface.