On the use of a multicriteria decision aiding tool for the evaluation of comfort

Öztürk Meltem [1] (*), Tsoukiàs Alexis (*) and Guerrand Sylvie (+)

(*) CNRS - LAMSADE, UniversitÈ Paris Dauphine, France
(+) SNCF, France

1 Problem definition

In this study we are interested in defining and evaluating the coach comfort for the French national railways, SNCF. More precisely, we conducted a feasibility study about the use of a multicriteria decision aiding tool within the ACONIT project [2] assigning comfort in high speed passenger trains. The main idea of this project consisted in considering the comfort as a judgment based on a set of complex elements by taking into account the traveller's point of view. This project was focused on two key points : 1. the comfort is a notion integrating different concepts which may be objective or subjective ; 2. the perception of the comfort by the passengers may be different from the definition of the comfort given by the SNCF experts. The first part of the ACONIT project focused on the comprehension of this complex notion of comfort and tried to define it from the passengers point of view. Before the ACONIT project, comfort was defined only by the experts of SNCF ; for instance seating comfort was defined using robots and technical informations such as resonance, vibration, vision, etc. The ACONIT project was interested in a similar subject but under a different perspective : "how is comfort appreciated by passengers ?". During the first part of the ACONIT project, different surveys have been realized with the SNCF passengers, experts and a supporting team of psycholinguists in order to understand how passengers perceive and define comfort.

The study presented in this article has been conducted at the last step of the ACONIT project and was focused on structuring the knowledge acquired in the preliminary steps. It was a three months feasibility analysis where two

1. This paper has been initiated while Meltem Öztürk was in CRIL-CNRS, Université d'Artois, France

2. Global approach for assessing the comfort components and their interaction for long range trains

specialists of multicriteria decision making (MCDM) worked in collaboration with the SNCF Comfort department. The role of the MCDM experts was to guide the Comfort department to put together different results and provide a global vision of the comfort ; to analyze existing methods and to propose an adequate method for the evaluation of the comfort. Because of confidentiality reasons the ancient methods can not be presented in this article. We just want to mention that these were basically based on weighted sums with some flexibility scales. Results of the previous steps of the ACONIT project have shown that there are three main types of comfort :

- Quality of the services proposed by the SNCF (on-line booking, service for disabled persons, service on the train (restaurants, controllers, etc.), quality of train connections, etc.) ;
- comfort on the train (seats, sensorial aspects like noise, vibrations etc., place for the baggages, etc.) ;
- comfort of the train stations.

The SNCF decided to focus their efforts firstly on" the comfort on the train". The issue was how to put together different aspects of rolling materials in order to build an overall assessment of comfort compatible with the passengers perception. Our contribution to the ACONIT project was exactly on that issue. Some previous studies in the literature have shown the complexity of the task of "how to define the confort" ([1] for confort in general, [8] for confort in a car, [6] from the railway point of view).

Before describing the model we have to fix the perspectives under which the model was expected to be used : why is evaluating comfort a problem and for whom and for what purpose ? Naturally the comfort on passengers trains is strongly related to the quality and the description of the rolling stock. The purchase of such stock is done through call for tenders. For the purchase or renovation of a coach the acquisition department prepares a call for tenders by specifying some needs (dimensions of the seats, material of the seats, distance between foot-rest and the seat, etc.) and evaluates them from especially two points of view : the cost and the number of specifications satisfied by the supplier. The final aggregation is done using a weighted sum.

Before our study, even if some specifications were directly related to the notion of comfort, the global evaluation of offers did not provide a view of the comfort level of each offer. On the other hand, the specifications within the call for tenders related to the comfort were defined by the acquisition department above while the ACONIT project has shown that the vision of comfort of this department could be different from the vision of some experts and from the passengers perception. For all these reasons the comfort department decided to develop a tool in order to propose an evaluation of suppliers' offers from the comfort point of view where the notion of comfort would be in coherence with the perception of the acquisition department but also with the experts and the passengers point of view. Since there are a number of different components determining the comfort, it has been decided to do a feasibility analysis for the use of a multicriteria decision aiding tool where different components of comfort would play the role of criteria. The evaluation of offers from the comfort point of view would be in term of a classification, *i.e.* pre-established classes would present different comfort level. This choice was related to some semantical and mathematical reasons that we will present in the rest of this article.

The feasibility analysis has been done in four steps :

– Definition of comfort integrating the passengers perception through the previous steps of the ACONIT project ;
– Construction of a hierarchy of the comfort components ;
– Definition of value scales for the evaluation of the comfort components ;
– Proposition of a classification model.

We present in Section 2 different components of comfort and we propose a hierarchy of such components in Section 3. The fact that comfort components are of different nature imposes a detailed study of their value scales, Section 4 gives some details on this subject. Section 5 shows basic notions related to the classification method that we chose, Section 6 provides decision parameters related to comfort components and chosen classification methods and finally Section 7 presents some examples.

2 Comfort Components

In this first step we tried to give a definition of the comfort from the passengers point of view. This construction step and the proposition of the model were the most important part of our study. As it has been already mentioned in the literature by a number of authors structuring a MCDA problem is very crucial ([4], [9], [7]).

The data which we dealt with in this part arised from surveys done within the framework of a thesis on psycholinguistic ([5]) conducted on the survey used by the SNCF. The aim of this PhD thesis was to define comfort on the train and analyze it from the linguistic point of view. Methodologies used in this thesis were based on the relation between the cognition and the linguistic and different surveys were designed in order to understand how passengers "feel" the comfort. A first survey, called *exploratory*, was used in order to build the *main* inquiry by enabling to clarify the shape of more relevant and more productive questions. The *main* survey was formed from fifteen open written questions and 240 passengers answered to the questions. The answers of the passengers were analyzed from the cognitive linguistic point of view which is more convenient in the case of open questions. Hence different linguistic technics are used during the analysis. Syntactical and morphological tools led to the naming of various semantic categories defining the global comfort. For instance, each syntagm (syntactical unit) was studied in order to identify different nomination ways of the comfort and the implication of the use of substantives, verbs, adverbs, adjectives, concession or opposition pointers, etc. Seventy-seven categories were defined from the answers of the questioned passengers. They were then classified in twelve meta-categories. Table 1 shows these categories.

Our commitment being to implement a model of comfort to use in rolling stocks acquisition call for tenders, we analyzed more in detail these semantic categories in order to be able to select those that seemed relevant for the preparation of call for tenders. This analysis was done by the two MCDM experts who proposed to the Comfort department of the SNCF a list of components defining comfort on the train. After a discussion little modifications have been asked by the SNCF. We present in the following the final version of this list.

It is also necessary to clarify that even if the surveys were mainly related to the comfort on the train, passengers mentioned also issues related to other types of comfort (bookings, strikes, connections, etc.). For that reason among such categories there were some which were not relevant for our study. Hence we began our analysis by a detailed study of these categories and subcategories. At this step, the components of comfort were analyzed one by one from a team formed by perception experts of SNCF, experts from the comfort and the acquisition departments and decision experts. Such an analysis led to dropping off some meta-categories or categories. We first present some examples of different dropping off reasons and then list the abandoned meta-categories.

– Dropping off of meta-categories which were not related to the comfort on the train : The meta-category called *comfort before and after the train* which contained categories like *booking facilities, access to the*

Comfort before and after the train	access to the train, station, reservation, nombre of people waiting for the train
General aspect	activity
Sensorial	air, atmosphere, noise, train movement, color, space, light, material, carpet, landscape, cleanliness, toilet cleanliness, security, temperature, air-condition, visibility, smell
Seating comfort	arm-rest, head-rest, back comfort, leg comfort, internet connexion, garbage, net, passengers movements, functionality, socket, foot-rest, train direction, table
Stand up comfort	corridor , door
Relational	crowd, other passengers, civicism,, shifting of passengers, efficiency of SNCF staff, intimacy, presence of non real passengers
Services	bar, material disadvantages, information multi-media, personnalization catering, phone, toilets animals, nursery
Train	being practical, compartmentalization, number of places, location, functionality, condition of transportation, door, luggage places, maintenance, classes, material,train dimension, being soft
SNCF image	modernity
Temporal aspect	trip time, speed, punctuality
Emotional aspect	passengers emotion, train level, experience, pleasure
Financial aspect	restoration cost, ticket cost

TABLE 1 – Comfort model given by the SNCF

train, location of train stations, etc. did not directly relate to the comfort on the train, hence it was abandoned. However the elimination of each category was discussed by the team participants (SNCF experts, and decision aiding experts) ; such discussion provided a better understanding of categories and allowed some modifications or addition of new categories. For instance, the category *reservation facilities* had a number of sub-categories : the possibility to choose the direction of the seat (in the same direction of the train or not) was one of them. With the new technologies its is possible to have seats with a convertible back (this option is generally not chosen because of its cost). Even if this notion was really related to reservation, it showed that people were sensitive to the direction of their seat. For that reason, a new category was added into the meta-category *seating comfort* showing if the direction of seats is convertible or not. Similarly, the category *access to the train* related to the equipment for disabled people or people having luggage was moved to the meta-category *service* with a restriction of its contents, naturally the presence of elevators etc. was eliminated.

– Dropping off of some categories which were irrelevant to the rolling stock quality even if they were related to the comfort in the train : After a discussion it was decided to abandon the categories *landscape, maintenance, punctuality, trip time, speed, efficiency of the SNCF staff, ticket cost, presence of non real passengers* (beggars, etc.), *restoration cost.* Such a decision was confirmed by the fact that such categories have been identified as*uncharacteristic* components of comfort in previous steps of the ACONIT project.
– Some other categories were also ignored for other reasons :
  – they were very general (for instance *condition of transportation*),
  – they were redundant with other categories (for instance *personal characteristics* and the categories of *disabled people, smokers*, etc.)
  – they were blurred and/or not frequently expressed (for instance *being soft, train dimension, functionality*).

  Such eliminations were also justified by the weak frequencies of such items in the answers directly related to the comfort in the train.

After our analysis, seven meta-categories were dropped off, five were retained and a new one was added. Some more comments are given in the following for specific reasons of abandoning each category :

– the meta-category *before-after the trip* : as it is mentioned before this meta-category was not directly related to the comfort on the train. Only the category *access to the train* was retained and moved to the meta-category *stand up comfort*

- the meta-category *generic aspect* : all its categories, except the *activity*, being too general were redundant with other categories. Answers to surveys and other studies done by the SNCF have shown that the practice of an activity (reading, writing, working with a laptop, etc.) becomes more and more important for passengers. For that reason it was decided to create a new meta-category named *activity*.
- the meta-category *relational* : some of its components being directly related to the personality of people were abandoned. The others, *number of passengers, shifting of passengers* and *intimacy* became sub-categories of the category *atmosphere Sensorial* meta-category.
- the meta-category *train* : some categories were rebuild : *compartmentalization, localisation, number of places, door* and *luggage places*. The *compartmentalization* (coaches for different types of people and their activities) was divided into two sub-categories : *disabled people, pregnant women*. These categories were then placed into the meta-category *Services*. The *number of passengers*, influencing the perception of ambiance is placed into the category *atmosphere*. The *door* has appeared in the majority of answers related to the moving on the train and noise, hence it was placed in two different meta-categories, *sensorial* and *stand up comfort*. Finally, the *luggage place* was placed into the meta-category *service*.
- the meta-category *temporal aspect* : under the hypothesis that the speed of the train does not depend on the suppliers (but depends on the railroad company) all the components of this meta-category were abandoned.
- the meta-category *financial aspect* : its components being not directly related to the comfort in the train were abandoned.
- the meta-category *emotional feeling* : its components *pleasure* and *experience*, the first one being redundant with other categories and the second one being not related to our framework were abandoned.

We give now some details about the five retained meta-categories.

- the meta-category *Sensorial* : it was divided into five categories *sound, visual, air-conditioning, atmosphere* and *security feeling*. An analysis of dependency showed that a majority of such categories were perceived simultaneously.

- the meta-category *Seating comfort* : it was divided into ten categories *arm-rest, head-rest, back, leg comfort, net, garbage, foot-rest, direction, train movement* and *table.*
- the meta-category *Stand up comfort* : it was divided into five categories *corridor, access to the train, door* and *movement of the train.*
- the meta-category *Activity* : it was divided into eight categories *multimedia, socket, internet connection, light, table, visibility, ambiance* and *seating comfort.*
- the meta-category *Service* : it was divided into nine categories *restaurant, information, toilet, nursery phone, luggage, disabled people, pregnant women* and *animals.*

3 Model

This second stage consisted in the constructing a hierarchy of the comfort components.

The procedure that we undertook in this stage was the following : the MCDM experts proposed a hierarchical model to the Comfort department of the SNCF. The SNCF approved the schema of the model.

The nature of the comfort components and the results of the previous steps of the ACONIT project were the main reasons for choosing a hierarchical model. Some previous studies regrouping some of the comfort components in different classes have been already done from a psycholinguistic point of view by M. Mzali ([10]). Our model completed this one.

A hierarchical model was defined as various levels, the highest level represented the global purpose. Within our framework, the highest level represents the comfort in the train which was decomposed in different parts named *meta-categories* which were decomposed in smaller parts, entitled *categories*, and so on... Such a model can be represented in a graphic way by a tree where the root represents the global purpose, nodes are the main components of the global purpose and leaves (nodes having no branches) are the components of the lowest level.

The choice of a hierarchy had certain advantages, (the interested reader may find some examples of such models in [2], [3]) : We obtained a simple representation of our model, the decomposition at several levels facilitates the aggregation procedures

The construction of the hierarchy of comfort was done using information from previous steps of the ACONIT project :

- We used basically the hierarchy determined by the PhD thesis
- During the PhD thesis a dependency analysis between different comfort components has been done. Some “father and son” and “brothers” dependencies are found during this analysis, which helped us to define the relations between some categories and meta-categories.
- Answers in inquiries to some questions which were directly related to one of the meta-categories showed also “father and son” relations.

Confort on the train

Sensorial comfort	Sitting comfort		Stand up comfort	Activity comfort	Service comfort
Sound	Arm-rest		Corridor	Multimedia	Bar/restorant
Visua	Leg comfort		Acces to the train	Socket	Information systems
Air-conditionning	Seat back net		Door	Internet connection	Toilet
Atmosphere	Direction		Train movement	Light	Nursery
Security feeling	Train movement			Table	Phone
	Garbage	size		Visibility	Luggage
		ergonomy		Atmosphere	Disabled people
	Table	volume		Sitting comfort	Pregnant woman
		ergonomy			
	Head-rest	angle			
		sensorial			
	Back comfort	width			
		length			
		hardness			
		uniformity			
		angle			
	Foot-rest	widht			
		slippiness			
		distance			

Table 2 – Hierarchy of comfort on the train

The basic levels of the hierarchical model of the comfort components proposed in this study are presented in Table 2. Five meta-categories are retained : *sensorial comfort, seating comfort, stand up comfort, activity* and *services*. These meta-categories have a number of categories which are also shown in Table 2. Some of these categories are divided in sub-categories, etc. Because of lack of space we only show the sub-categories related to the seating comfort in Table 2 since in the rest of this paper we are going to develop only the aggregation of seating comfort components.

We were interested in a feasibility analysis showing the interest of a multi-criteria decision aiding tool summarizing passengers evaluation of the comfort for rolling stock procurement. This evaluation aimed at allocating suppliers' offers to different categories representing the level of comfort of their proposition. Under such a perspective and for this specific purpose our model showed that global comfort could be divided into five meta-categories which were then divided into categories which were divided into sub-categories. In the rest of this paper, we are going to present and discuss the evaluation of one of the meta-categories, *seating comfort* ; the evaluation of the others being similar. This choice is related to the importance and the complexity of *seating comfort* . It had many categories with different nature and these were generally divided into sub-categories combining experts' opinion, surveys' results and the team's point of view.

4 Value scales for *seating comfort*

The components of *seating comfort* were of different nature and both qualitative or quantitative data could be used. Such a diversity imposed the use of different types of scale for different components.

The construction of such scales was done by the MCDM experts, one comfort engineer and one perception expert. In fact the SNCF has an *Equipment Department* which is specialized in the definition of a "good" ("acceptable" or "comfortable") equipment (for instance the minimum distance between the seat and the foot-rest must be 850 *mm*). A number of perception experts working at this department defined physical indicators through some physical experiences. The majority of the values presented in this part came from these indicators.

The construction of such scales being an important step of our analysis, we devote this section to this issue.

Before giving more details about different types of scales used in our analysis, we present different categories (and their sub-categories) of the *seating* *comfort* :

- *arm-rest :* its evaluation was done by perception experts who classified it among five options : *bad, not bad, normal, good* and *very good.*
- *head-rest :* its evaluation was the result of an aggregation of assessments on two sub-categories named *angle of head-rest* and *sensorial of head-rest* (perception of head-rest). Such an aggregation was used in order to class an object into three ordered categories : *bad head-rest comfort, normal head-rest comfort* and *good head-rest comfort.*
  i. *angle :* its evaluation was done by binary data : 1 when passengers can change the angle of the head-rest and 0 otherwise.
  ii. *sensorial :* its evaluation (integrating maximal acceptable pression in the contact area, the repartition of soft material and resistance to damages) was done by perception experts who gave scores between 0 and 10 (10 being the best score).
- *back comfort :* its evaluation was the result of an aggregation of assessments of five sub-categories named *width, length, hardness, uniformity* and *angle*. Such an aggregation was used in order to have five ordered categories for *back comfort* (bad, not bad, normal, good, very good).
  i. *width :* this was the width while seated ; its value was presented in *mm* and the minimum acceptable value for SNCF was 450*mm*.
  ii. *length :* this was the width while seated *en charge*, its value was presented in *mm*.
  iii. *hardness :* this was the hardness of the *dossier* and *fessier*. It was evaluated by perception experts and graded between 10 and 0 (10 being the best score).
  iv. *uniformity :* it showed the presence or absence of hard parts. Its was evaluated by perception experts and graded between 10 and 0 (10 being the best score).
  v. *angle :* as the angle of head-rest, its evaluation was done by binary data : 1 when passengers could change the angle of the back of the seat and 0 otherwise
- *leg comfort :* its evaluation was the distance between the seat and foot-rest (in *mm*).
- *net :* its evaluation was done by perception experts who gave notes between 0 and 10 (10 being the best score).
- *garbage :* its evaluation was the result of an aggregation of the evaluation of its two sub-categories named *size* and *ergonomy*. Such an aggregation was used in order to have three ordered categories for *gar-*

bage.

  i. *size :* its evaluation was qualitative but ordinal with three levels : *small, normal, big.*
  ii. *ergonomy :* its evaluation was done by perception experts who gave notes between 0 and 10 (10 being the best score).

– *foot-rest :* its evaluation was the result of an aggregation of the evaluation of its three sub-categories named *width, slipperiness* and *distance.* Such an aggregation was used in order to have three ordered categories for *foot-rest.*
  i. *width :* its evaluation was in mm and the minimum acceptable value for SNCF was 300mm.
  ii. *slipperiness :* Its showed the quality of having a non skid surface. The experts evaluated it by three levels : *good, normal, bad.*
  iii. *distance :* this was the distance (in mm) between the surface of foot-rest and the sole of the seat.

– *direction :* it showed the presence or absence of double numbering of seats (in this case the numbers of seats could be changed by the SNCF, hence for a given travel the SNCF could know which seats would be in the same direction as the train movement). It had a binary evaluation, 1 (resp. 0) representing the presence (resp. absence).

– *movement of train :* its evaluation was done by perception experts who gave notes between 0 and 10 (10 being the best score).

– *table :* its evaluation (score between 0 and 10) was the result of an aggregation of the evaluation of its two sub-categories named *bulk* and *ergonomy.*
  i. *bulk :* its evaluation was done by perception experts who gave notes between 0 and 10 (10 being the best score).
  ii. *ergonomy :* its evaluation was done by perception experts who gave notes between 0 and 10 (10 being the best score).

Table 3 summarizes the scales of the categories and the sub-categories of the *seating comfort* meta-category.

In order to perform the measures on parent roods of the hierarchy above presented, we could use different procedures, not necessarily the same. The last level aggregation has been done using the ELECTRE TRI method (we explain this choice in the following section). Other procedures have also been tested and used for simple aggregation issues.

Category	***Category Scale***	***Sub-category***	***Sub-category Scale***
Arm-rest	bad, not bad, normal, good, very good	-	-
Head-rest	bad, normal, good	angle	$\{0, 1\}$
		sensorial	$\{0, \ldots, 10\}$
Back comfort	bad, not bad, normal, good, very good	width	$[400, 650]$
		length	$[500, 700]$
		hardness	$\{0, \ldots, 10\}$
		uniformity	$\{0, \ldots, 10\}$
		angle	$\{0, 1\}$
Leg comfort	$[850, 980]$,	-	-
Net	$\{0, \ldots, 10\}$	-	-
Garbage	bad, normal, good	size	bad, normal, good
		ergonomy	$\{0, \ldots, 10\}$
Foot-rest	bad, normal, good	width	$[200, 600]$
		slipperiness	bad, normal, good
		distance	$[80, 200]$
Direction	$\{0, 1\}$	-	-
Train Movement	$\{0, \ldots, 10\}$	-	-
Table	$\{0, \ldots, 10\}$	volume	$\{0, \ldots, 10\}$
		ergonomy	$\{0, \ldots, 10\}$

TABLE 3 – Scales of *seating comfort* components and sub-components

5 The Electre TRI method as the evaluation tool of our study

We were looking for the intrinsic evaluation of the offers and not for just a ranking. The reason was that within a ranking approach the comparison of each pair of objects did not provide information about the quality level of the objects. For instance, if a ranking approach provides the following ranking from the best to the worst : *Offer 1* $\succeq$ *Offer 2* $\succeq$ *Offer 4* $\succeq$ *Offer 3*, we know that *Offer 1* is at least as good as *Offer 2* but no one can guarantee that *Offer 1* has a "good comfort". The intrinsic evaluation had to be performed despite the presence of quantitative information. This practically amounts in classifying the offers in pre-defined ordered classes ; such a problem statement is called *sorting* in the literature.

We chose to work with five categories representing *very bad, bad, intermediate, comfortable, very comfortable* levels. Note that such a categorization is an ordered one by nature and the number of categories could be changed if one wants more or less detailed results. Since such categories are ordered (category *comfortable* is better than category *intermediate* etc.) one can separate them with some frontiers. This is what the ELECTRE TRI method is doing for the sorting problem situation.

5.1 Why Electre TRI ?

The ELECTRE TRI method is a multicriteria decision aiding tool designed for sorting problems. Sorting problems consist in analyzing the intrinsic value of each object to be classified in order to propose an appropriate recommendation for each one. The ELECTRE TRI consists in allocating each object into one class. Classes are ordered (good, intermediate, not good, etc.) and are defined by the decision maker. The characterization of each class is done by defining frontiers between classes. Such frontiers are called the *limit profiles.*

The assignment of an object into a class is done by the help of the comparison of this object with the limit profiles. Objects to be classified are not compared to each other, hence the assignment of one object to a class is completely independent from the evaluation of another object. The comparison between an object and a limit profile is done by a binary relation called *outranking relation.*

The use of the outranking relation which is based on majority principal, contrary to what happens with the methods based on the weighted sum principle, does not allow compensation between different performances of the object according to different criteria (for instance a very good evaluation for *seating comfort* can not compensate for a bad evaluation on *stand up comfort*).

Moreover, compensatory methods need to impose commensurability of scales of the different attributes on which the criteria are established. In our framework different types of scales with different domains are used, hence such an approach would need supplementary studies in order to define such a common scale for all the components. Such a study needs a very strong interaction between different agents of the problem (decision experts, perception experts, people from comfort and acquisition department, etc.), can take a long time and may be difficult (for instance we have to be capable to say how many centimeters we have to increase the distance between the foot-rest and the seat if the garbage looses 8 mm^3 of its volume). As in the previous example the compensation may be relatively difficult to be expressed in some cases.

Briefly, the definition of our problem (allocation of offers into ordered categories), the nature of the comfort components (presence of qualitative data, different value scales and different value domains), our preference for a non compensatory method and our will to have a method where the assignment of objects are independent from each other were the main reasons for choosing the ELECTRE TRI for our problem. However as it will be explained in the rest of the paper, the evaluation of offers according to some sub-categories may be done by other methods.

The interested reader can find more details about the ELECTRE TRI in Appendix.

6 Decision parameters

Let us remind that in this section we are only interested in the *seating comfort* selected as an example.

6.1 Importance parameters

The construction of the importance parameters for the *seating comfort* was based on an analysis done before our study. This analysis was done by the SNCF experts and a PhD student on psycholinguistic. In their study, the SNCF people calculated the frequency of answers of passengers to some questions. Such frequencies were presented in their study in two parts : the ones related to a positive evaluation of the comfort and the others related to a negative evaluation. We used the sum of these frequencies in order to get an idea of the importance of different categories. Table 4 shows this evaluation.

	Positive answers	***Negative answers***	***Total answers***	***Weight***
Arm-rest	1	2	3	3/176
Head-rest	0	5	5	5/176
Back comfort	37	25	62	62/176
Leg comfort	2	42	44	44/176
Net	0	3	3	3/176
Garbage	0	5	5	5/176
Foot-rest	3	2	5	5/176
Direction	1	7	8	8/176
Train movem.	4	27	31	31/176
Table	4	6	10	10/176
TOTAL	52	124	176	1

TABLE 4 – Frequency of answers and weights

6.2 Thresholds

Concerning the majority threshold, we chose to make use of the default value of the ELECTRE TRI, 0.76. This value means that in order to say that object x is at least as good as a limit profile, at least 76% of criteria must be in concordance with this affirmation (naturally after the weighting).

Veto thresholds helped us to give up an assignment into a class if the offer was not strong enough according to one or more important criteria even if the majority (more than 76% of criteria) was for this assignment. We decided to define three veto thresholds for the most important criteria, *back comfort*, *leg comfort* and *train movement*. We set these thresholds to 1 for *back comfort*, to 3 for *train movement* and to 30 for *leg comfort*. A veto threshold fixed to 1 represented a very strong demand for the evaluation of its criterion. For instance, concerning the *seating comfort*, if the limit profile between the classes *very good* and *good* required a *very good* evaluation for *back comfort*, an offer having a *normal* evaluation for *back comfort*, it could never be classed into the *very good seating comfort* class. Note that the smaller is the veto threshold, the stronger is its power.

The introduction of indifference thresholds was not judged necessary because of the small number of levels of scales.

6.3 Limit profiles

The limit profiles are imaginary objects representing the limit between two consecutive classes. Figure 1 shows a graphical representation of classes where g_i represents the *ith* criterion, C_k the *kth* class and a_j the limit profile between the classes C_{j-1} and C_j. The limit profiles a_0 and a_m were omitted in our study.

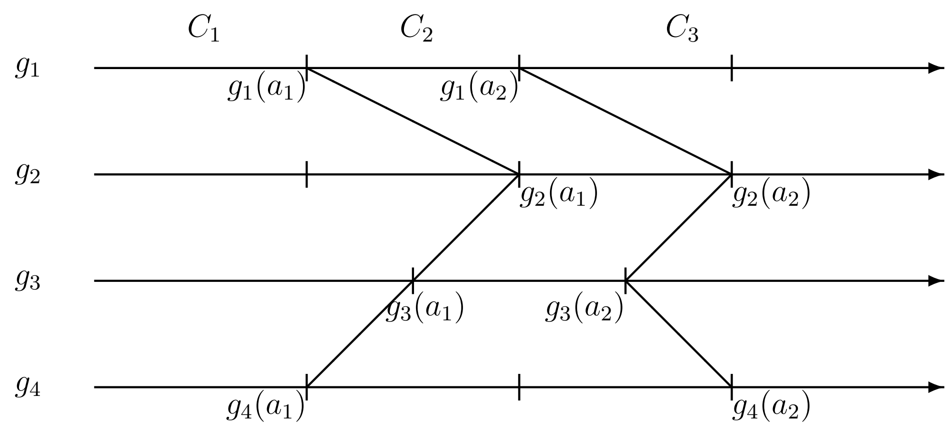

FIGURE 1 – General graphical representation of classes

The definition of classes and the characterization of limit profiles were done by MCDM experts in collaboration with the Comfort department. The definition of the limit profiles was done by the help of some intuitive allocation examples. For instance the MCDM experts showed a fictitious offer (for instance very bad in almost all criteria except back comfort) and asked to comfort engineers in which category they wanted to put it. We defined five ordered classes for *seating comfort* and called them *very bad, bad, normal, good* and *very good*. Four limit profiles, a_1, a_2, a_3 and a_4 were defined in order to separate these classes. The profile a_1 separated the class *very bad* from the class *bad*, the profile a_2 separated the class *bad* from the class *normal*, etc. The evaluation of profiles for *seating comfort* components is showed in Table 5. Naturally such evaluations depended on the value scales defined in Section 4. A graphical representation of such classes can be found in Figure 2.

	Frontier a_1 ***bad- not bad***	***Frontier*** a_2 ***not bad- normal***	***Frontier*** a_3 ***normal- good***	***Frontier*** a_4 ***good- very good***
Arm-rest	not bad	normal	good	very good
Head-rest	normal	normal	good	good
Back comfort	not bad	normal	good	very good
Leg comfort	850	920	950	970
Net	4	6	7	9
Garbage	normal	normal	good	good
Foot-rest	normal	normal	good	good
Direction	0	0	1	1
Train movem.	4	5	6	8
Table	4	5	6	8

TABLE 5 – Presentation of limit profiles for *seating comfort*

6.4 Aggregation of sub-categories

Some of the *seating comfort* components had sub-components. The evaluation of such components could be done by different aggregation methods on their sub-components. We present in the following such aggregation procedures.

6.4.1 Head-rest comfort

There were two sub-categories : *angle* and *sensorial*. These sub-categories were defined with different types of scales (binary data for *angle* meaning that

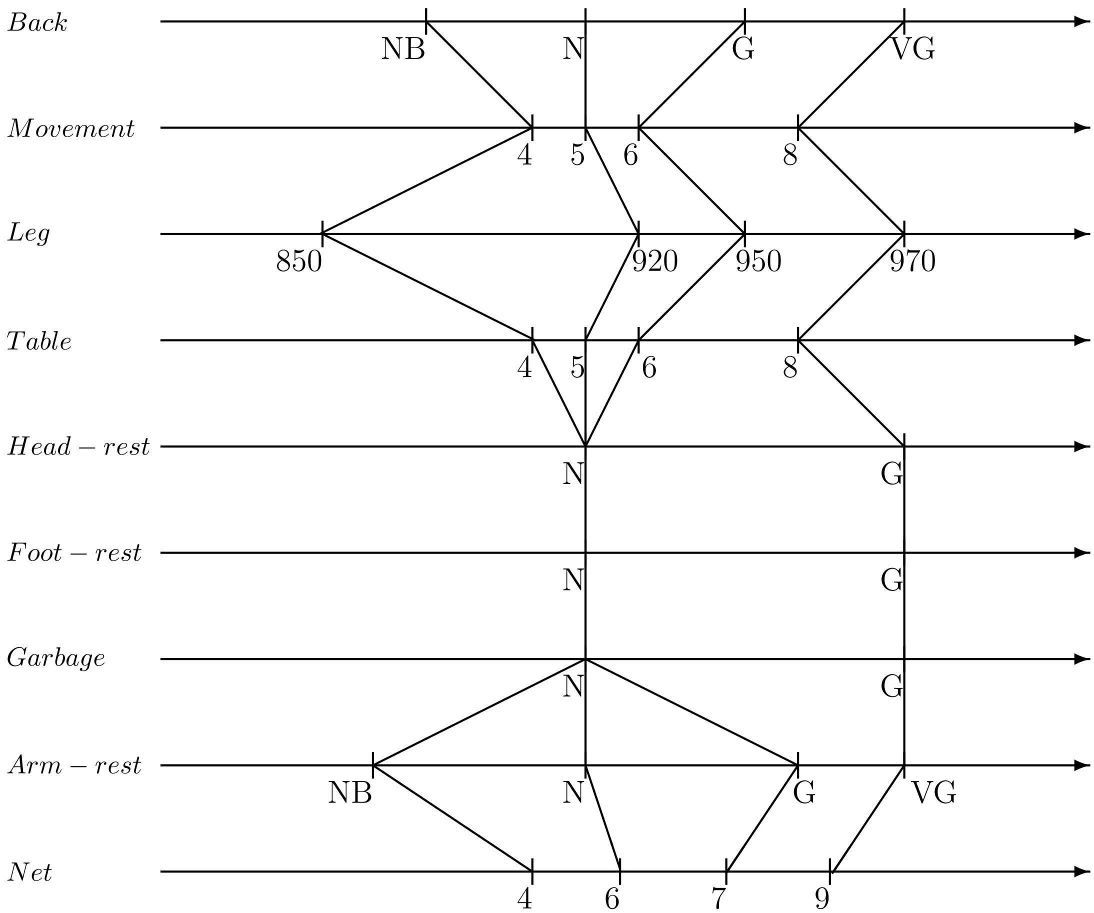

FIGURE 2 – Seating comfort classes

the angle of the head-rest could be changed and scores gave by experts for *sensorial*, score between 0 and 10) and the final recommendation on *head-rest comfort* was a classification in three ordered classes (*bad, normal* and *good*). The classification was done with simple rules :

- if angle is one and sensorial note is more than 7 then the evaluation is good,
- if angle is one and sensorial note is between 4 and 7 then the evaluation

is normal,
– otherwise the evaluation is bad.

6.4.2 Back comfort

There were five sub-categories called *width, length, hardness, uniformity* and *angle*. As in the case of *head-rest comfort* these sub-categories were defined on different types of scales (interval scales, binary data or ratio scales). In order to deal with this scale's diversity and to not allow compensation, the ELECTRE TRI method was again used. The final recommendation was about the assignment of offers into five ordered classes *very bad, bad, normal, good* and *very good* back comfort. Table 6 presents limit profiles of this component. No veto or indifference thresholds were defined and the majority threshold was fixed to 0.76.

Back Comfort	a_1 ***Frontier bad not bad***	a_2 ***Frontier not bad normal***	a_3 ***Frontier normal good***	a_4 ***Frontier good very good***
Widht	450	460	480	550
Lenght	530	550	550	550
Hardness	0	1	1	1
Uniformity	4	6	8	9
Angle	8	8	10	10

TABLE 6 – Presentation of limit profiles for back comfort

6.4.3 Foot-rest and garbage comforts

There exist two sub-categories, *size* and *ergonomy*, for the component *garbage* and three sub-categories, *width, slipperiness* and *distance*, for the component *foot-rest*. We used a rule based method for the evaluation of garbage comfort : if size is big and the note of ergonomy is grather than 7 then the garbage comfort is good, otherwise if size is normal or big and the note of ergonomy is grather than 4 then the garbage comfort is normal and in all the other cases the garbage comfort is bad. Again for scale and non compensation reasons and the final recommandation being a classification, the ELECTRE TRI method was used for foot-rest comfort. Figure 7 presents the limit profiles of classes.

Foot-rest	a_1 ***Frontier bad/normal***	a_2 ***Frontier normal/good***
Width (mm)	300	400
slipperiness	normal	good
Distance (mm)	130	130

TABLE 7 – Presentation of limit profiles for foot-rest

6.4.4 Table comfort

There were two sub-categories, *volume* and *ergonomy*, both of them defined on a ratio scale ($\{0, \ldots, 10\}$) representing the scores given by experts. The aggregation method could provide a score for *table comfort* as it is shown in Table 3. For this aggregation a weighted sum was used with the substitution rates presented in Table 8. The score of *table comfort* of an offer x, denoted for instance by $g(x)$ is calculated by $g(x) = \sum_i w_i g_i(x)$ where $g_i(x)$ presented the score of x for the sub-component i and w_i presents the substitution rate of the sub-component i.

Table	***Substitution rate*** (w_i)
volume	0.5
ergonomy	0.5

TABLE 8 – Substitution rates for table

7 Examples

In this section we present three imaginary offers and analyze their assignment into different classes. Such examples were prepared in order to illustrate and explain the principles of the the ELECTRE TRI method (veto threshold, incomparability, optimistic and pessimistic procedures, etc.) . Table 9 represents the assessments of these three offers for the *seating comfort* components and sub-components. Such evaluations were chosen by MCDM experts.

In the following we will focus on the aggregation of the components.

7.1 Assignment of Offer 1 to the class *normal seating comfort*

We analyzed the outranking relations between *Offer 1* and the limit profiles for both the "optimistic" and "pessimistic" procedure :

- *Pessimistic procedure* : The procedure compared first of all the offer to the limit profile a_4 and then to a_3, a_2 etc. and stopped when the offer outranked a limit profile. *Offer 1* did not outrank profiles a_4 and a_3 and was indifferent to profile a_2 (indifference being a part of the outranking relation -x outranked y if and only if x was preferred to y or x and y were indifferent- *Offer 1* outranked a_2). Hence the procedure stopped and *Offer 1* was affected to *normal seating comfort* class.
- *Optimistic procedure* : The procedure began by comparing *Offer 1* to the limit profile a_1 (profile separating the lowest class C_1 from C_2), if limit profile as not preferred to *Offer 1*, the comparison procedure continued, *Offer 1* was compared to a_2, a_3, etc. limit profile a_1 was outranked by *Offer 1*, a_2 and *Offer 1* were indifferent and *Offer 1* was outranked by a_3 ; hence the procedure stopped and *Offer 1* was affected to the *normal seating comfort* class.

Table 9 presents the evaluation of *Offer 1* for the *seating comfort* components. This shows that the evaluation of *Offer 1* for the *back comfort, train movement* and *leg comfort* attributes are higher than the ones of the limit profile existing between classes *not bad* and *normal.* Hence we concluded that if the supplier wanted to improve his offer he must improve his offer from the *table* point of view, *table* being one of the important *seating comfort* components.

7.2 Assignment of Offer 2 to the class *good seating comfort*

Table 9 presents the evaluation of *Offer 2* for the *seating comfort* components. It is easy to remark that the veto threshold on *leg comfort* had a strong

		Offer 1		Offer 2	
		Sub-categories	**Global**	**Sub-categories**	**Global**
Arm-rest		-	normal	-	very good
Head-rest	*angle*	0	normal	1	good
	sensorial	4		8	
Back comfort	*width*	500	normal	510	good
	length	540		550	
	angle	1		1	
	hardness	6		6	
	uniformity	8		10	
Leg comfort		-	940	-	980
Net		-	2	-	9
Garbage	*size*	normal	bad	good	good
	Ergonomie	4		9	
Foot-rest	*width*	420	good	422	good
	distance	125		130	
	being slip	good		normal	
Direction		-	0	-	1
Train movement		-	5	-	8
Table	*bluck*	5	4	6	8
	Ergonomie	3		10	

		Offer 3	
		Sub-categories	**Global**
Arm-rest		-	normal
Head-rest	*angle*	1	normal
	sensorial	7	
Back comf	*width*	560	verygood
	length	550	
	angle	1	
	hardness	9	
	uniformity	10	
Leg comfort		-	930
Net		-	6
Garbage	*size*	bad	bad
	Ergonomie	6	
Foot-rest	*width*	430	good
	distance	131	
	being slip	good	
Direction		-	1
Train movement		-	5
Table	*bluck*	7	7
	Ergonomie	7	

TABLE 9 – Examples

influence on the assignment of *Offer 2* to the *not bad seating comfort* class. The evaluations of *Offer 2* were at least as good as (better than or preferred to) all the evaluations of the limit profile a_4 except the one of the *leg comfort*. Thank to these good evaluations *Offer 2* obtained a majority coalition in his favor against a_4 however the category *leg comfort* introduced a veto to the outranking of a_4 by *Offer2*. Hence *Offer 2*, instead of being classified into the *very good seating comfort* class was classified into the *good seating comfort* class only. This example showed the importance of the veto thresholds for imposing very good evaluations. In this example, if the supplier wanted to improve his offer he must improve his offer from *leg comfort* point of view.

7.3 Assignment of Offer 3 to two different classes *not bad seating comfort* and *good seating comfort*

We analyzed the outranking relations between *Offer 3* and the limit profiles for optimistic and pessimistic procedure since these two procedures did not provide the same assignment. Table 9 presents the evaluation of *Offer 3* for *seating comfort* components.

– *Pessimistic procedure* : The procedure compared first of all the offer to the limit profile a_4, *Offer3* did not outrank a_4. Then for the comparison of *Offer3* and a_3 and a_2 we got incomparabilities. The procedure continued, *Offer3* outranked a_1, hence the procedure stopped and *Offer3* was affected to *not bad seating comfort* class.
– *Optimistic procedure* : The procedure began by comparing *Offer 1* to the limit profile a_1 which did not outrank *Offer3*. Limit profiles a_2 and a_3 did not outrank *Offer 3* because of the incomparabilities. The profile a_4 was preferred to *Offer 3*, hence the procedure stopped and *Offer3* was affected to *good seating comfort* class.

This example showed the role of incomparabilities in the assignment difference.

8 Conclusion

In this paper we presented a real word application of muticriteria decision aiding : Evaluating suppliers offers to call for tenders in rolling stock procurement from the comfort point of view. Our study was used as a feasibility analysis for the introduction of multicriteria tools in the SNCF. The results found in this study were jugged to be interesting by the SNCF who wants now to use similar approaches for the evaluation of other comfort aspect and/or other components of offers to call for tenders. A PhD student began to work on this subject since april 2010.

The complex nature of comfort was presented here using a hierarchical model. In the paper we showed how and why to use such a model. The presence of different types of data, -qualitative, quantitative, binary, etc.- was handled using different methods on different nodes of the comfort hierarchy, with a special interest on outranking methods. The overall assessment resulting from the hierarchical aggregation of the values helped the SNCF to classify the suppliers offers into five comfort categories. Such a classification gave information about the quality of offers and allowed also negotiation with suppliers.

Our contribution being a feasibility analysis focused specially on the test of the use of data coming from the PhD thesis on psycholinguistic, some aspects of MCDA have been ommited, such as sensibility analysis, management of diverging opinions, etc. These aspects will be naturally taken into account in the final application of the MCDA tool.

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Appendix

The general procedure of the ELECTRE TRI has two consecutive steps :

- construction of a binary relation establishing how alternatives are compared to the boundaries of classes,
- exploitation (through assignment procedures) of the binary relation in order to assign each alternative to a specific class.

We present first of all the first step consisting in comparing alternatives to profiles representing the frontiers between ordered categories. We will note by X the set of objects to be classified (for instance suppliers' offers), $X = \{x_1, x_2, \ldots, x_n\}$, and by $A = \{a_0, a_2, \ldots, a_m\}$ the set of limit profiles. Let us denote by $C = \{C_1, C_2, \ldots, C_m\}$ the set of classes, the class C_1 being the worst one and C_m the best one etc. If we have m classes, we will have $m+1$ limit profiles where a_0 (resp. a_m) represents a fictive profile having the worst (resp. the best) evaluation on each criterion while a limit profile a_i, $i \in \{1, 2, \ldots, m-1\}$, represents the frontier between the classes C_i and C_{i+1}.

The comparison between two elements x and y (x may represent an object and y a limit profile or the inverse) is done by an outranking relation denoted by S. The affirmation xSy (or $S(x, y)$) means that "the element x is at least as good as the element y" and is calculated using two indices, the *Concordance* and the *Discordance* index. One can find different, more or less refined, definition of such indices in the literature but all of them are based on the same following idea :

- *Concordance index :* shows if there is a sufficiently strong majority of criteria in favor of the outranking relation ;
- *Discordance index :* shows if there is at least one criterion "strongly opposed" to the outranking relation (in such a case we say that the criterion has a veto for the outranking relation).

In the following we note $C(S(x, y))$ (resp. $D(S(x, y))$) in order to say that there is concordance (resp. discordance) for the outranking $S(x, y)$. Hence the relation $S(x, y)$ is verified if there is concordance but not discordance :

$$xSy \text{ if and only if } C(S(x, y)) \text{ and not } D(S(x, y))$$

We will present in the following a classical formule of concordance and discordance indices. The interested reader can find more detailed explanations on the subject in [11], [12]. The computation of these indices makes use of different parameters such as the importance of a criterion, the indifference threshold, the veto threshold and the majority threshold.

$$C(x, y) \iff \frac{\sum_{j \in J_{xy}} w_j}{\sum_j w_j} \geq \gamma, \tag{1}$$

$$D(x, y) \iff \exists j : g_j(y) - g_j(x) > v_j \tag{2}$$

where :

- g_j is a real valued function representing the evaluation of alternatives with respect to the criterion c_j (to be maximized) ;
- w_j is a non negative coefficient which represents the importance of the criterion c_j ;
- J_{xy} represents the set of criteria for which x is at least as good as y ; more precisely, $J_{xy} = \{j : g_j(y) - g_j(x) \leq q_j\}$ where q_j is the indifference threshold associated to criterion c_j ;
- γ is a majority threshold ;

– v_j is a veto threshold on criterion c_j ;

The majority threshold represents the minimum percentage of criteria (weighted according to their importance) needed in order to have a concordance. The veto threshold is used for the discordance index and represents for each criteria the threshold for which a difference of evaluation on this criterion becomes problematic for the construction of the outranking relation. The indifference threshold represents the maximum tolerated difference between evaluations of two objects x and y in order to say that x and y are indifferent. In what follows, we will assume, without any loss of generality, that preferences increase with the value on each criterion.

It is easy to see that comparing two objects x and y, four situations may appear :

– xSy and not ySx : we say that "x is preferred to y" ;
– not xSy and ySx : we say that "y is preferred to x" ;
– xSy and ySx : we say that "x and y are indifferent" ;
– not xSy and not ySx : we say that "x and y" can not be compared ;

The last case shows that the outranking relation is not necessary a complete relation.

After the construction of all comparisons between alternatives and profiles, the exploitation procedure begins. The role of this procedure is to analyse now which an alternative x compares to subsequent profiles in order to determine the class to which x should be assigned. The ELECTRE TRI proposes two different assignment procedures :

– *the pessimistic assignment procedure* :
  i. compare x successively to limit profiles a_i , for $i \in \{p, p-1, \ldots, 0\}$,
  ii. a_h being the first profile such that xSa_h, assign x to class C_{h+1}.

  If a_{h-1} and a_h denote the lower and upper profile of the category C_h, the pessimistic procedure assigns alternative a to the highest class C_h such that x outranks a_{h-1}, *i.e.*, xSa_{h-1}.

– *the optimistic assignment procedure* :
  i. compare x successively to a_i, for $i \in \{1, 2, \ldots, p\}$,
  ii. a_h being the first profile such that a_hSx and not xSa_h (*i.e.* x is preferred to a_h), assign x to class C_h.

  The optimistic procedure assigns x to the lowest class C_h for which the upper profile a_h is preferred to x.

The ideas that ground the two assignment procedures being different, these assignment procedures might assign some alternatives to different classes. The difference is basically related to the fact that the outranking relation is not complete, more precisely :

- when the evaluation of an alternative is between the two profiles of a class on each criterion, then both procedure assign this alternative to this class,
- a divergence exists among the results of the two assignment procedures only when an alternative is incomparable to one or several profiles ; in such a case the pessimistic assignment rule assigns the alternative to a lower class than the optimistic one.