CARTOPTI: A TOOL FOR AUTOMOTIVE SEAT CONCEPTION USING REGRESSION MODELS AND CUSTOMERS STUDIES

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ABSTRACT

The main purpose of our study is to propose a tool for automotive seat conception. Automotive seat comfort is usually a matter of technical experts. These specialists have not only technical skills but also a wide knowledge of our customers. They design Renault seats taking into account customers expectations and technical constraints. This approach has some limitations, well known by sensory scientists. One of the difficulties is the need of an iterative process to design seats: new seat proposal, tryouts, improvements, new seat proposal… The number of different seats increases each year as we have to reduce the number of expensive prototypes. Thereby, we suggested that the experts enhance their approach with Preference Mapping. Preference Mapping is one of the methods used in Sensory Science to establish relationships between sensory and customers' data in order to understand customers' preferences. This methodology is based on regression of each consumer's preference scores with the two first axes of a PCA with sensory attributes as variables.

We selected 9 seats with quite different sensory properties. 120 customers evaluated those seats. We used pressure measurements which take into account the interaction between the seat and the participant, as sensory ones. We carried on the previous improvements on preference mapping techniques by developing some specific functions: to estimate a comfort score for any new seat prototype without conducting other customers' evaluation, to provide target values to define the characteristics of an optimal seat with or without constraints on the technical parameters.

Keywords: *sensory science, preference mapping, instrumental measures, automotive seats*

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1. INTRODUCTION

Automotive seat comfort is usually a matter of technical experts. These specialists have not only technical skills but also a wide knowledge of our customers. They design seats taking into account customers expectations and technical constraints in order to obtain an ideal seat, which should be appreciated by the greatest number of customers [[1], [2]].

There are several ways to achieve this goal. The simplest way is to consider the best seat of the current market as a target to reproduce. As illustrated by Figure 1 (left side), the product F with the highest average score given by customers can be the target.

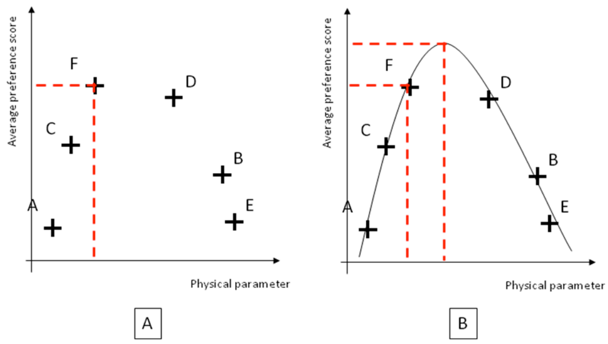

Figure 1: Illustration of two strategies to develop new products

A double risk is associated to this simplicity:

1) By “copying” an existing seat from the market, the seat designer takes the risk to have a delay compared to the genuine seat. When the “new” seat will be available on the market, the next one from the genuine manufacturer will be available already.

2) The target seat is perhaps the best on the market but nothing indicates that another seat not yet available on the market cannot be more appreciated.

Modeling customers’ preferences lowers these risks. On Figure 1 (right side), the preferences of the customers were modeled. The model highlights a specific value of the physical parameter which maximizes the preferences of the customers. It is this value which will be the target of the future seat. The capacity of prediction of the model makes it possible to choose the optimal product, even better than the best of the products tested.

External Preference Mapping (Prefmap) is one of the methods used in Sensory Science to establish relationships between sensory and customers’ data in order to understand consumers’ preferences. The objective of this type of methodology is to explain consumers' preferences with the sensory attributes of the products. This methodology is based on regression of each consumer’s preferences scores with the two first axis of the Principal Component Analysis (PCA) obtained from the sensory attributes.

Widely used in food and cosmetic industries [[3]], Prefmap is also used in automotive industry for braking systems [[4],[5]], seats [[6]] and car compartments [[7]]. As Prefmap was more and more used by seat designers, they asked for a tool which can ease the use of the technique and for several improvements.

2. EXTERNAL PREFERENCE MAPPING TECHNIQUE

External preference mapping techniques allow establishing relationships between:

- The data provided by a sensory profile: an "objective" description of all the sensations perceived by customers evaluating a set of products. The methodology widely used for the sensory profile is the conventional profile [[8]]: a small group of trained subjects describe their sensations with a common lexicon.
- The data provided by a customer study with the same set of products. The methodology is proposed by AFNOR [[9]]. About 100 customers evaluate the same products using preference scores.

Thus, external preference mapping is based on a sensory map obtained by PCA of the sensory profile data. This type of map describes the relative positions of the products according to the sensations they provide. The postulate of the external Prefmap is that two products close to each other on the sensory map must have close preference scores.

The first stage of Prefmap is the modeling of the preferences for each customer. A 3D graph is associated to each consumer. Each point represents a product. The first two coordinates (X1, X2) correspond to the coordinates of the products resulting from the PCA of sensory measurements. The third coordinate Z corresponds to the scores of the customer (Figure 2 – left side). The modeling of the preferences is represented by a surface (Figure 2 – right side). By using this graph, it is possible to estimate the score of this customer for each product of the sensory map, even if this product does not exist or if the subject did not evaluate it.

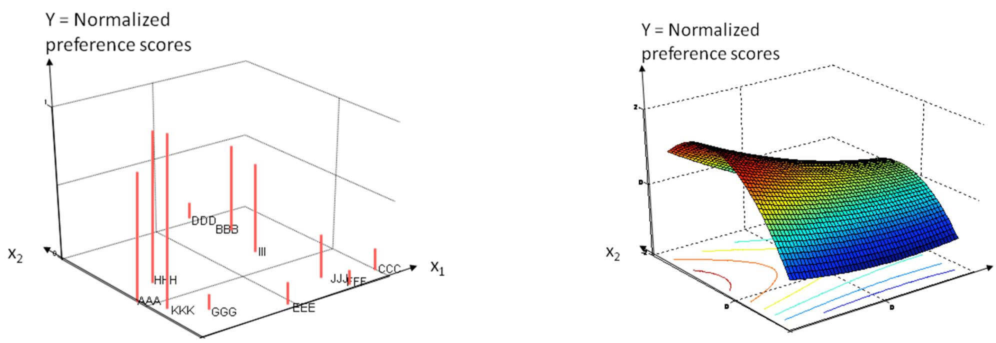

Figure 2: Example for one customer of the representation of preference scores and associated model

The model is based on the quadratic equation:

$$Y = a_0 + a_1x_1 + a_2x_2 + a_3x_1^2 + a_4x_2^2 + a_5x_1x_2$$

In this equation, Y is the vector of normalized preference scores of the customer, for all the products. $(x_1;x_2)$ is the matrix of coordinates of these same products from the two first axes of the sensory data PCA. Prefmap method uses four sub-models: the vectorial model, the circular model, the elliptic model, the complete quadratic model.

1. **The vectorial model**: a_3, a_4 and a_5 are null. A minimum of 4 products is necessary to use the vectorial model. It adjusts a plan with to the preference scores. It gives the direction of the preferences of the customer: the more intense the feeling is, the more the customer appreciates. It does not allow modeling a customer who would like two products with opposite sensory characteristics.

2. **The circular model**: $a_3 = a_4$ and a_5 is null. It requires at least 5 products. It makes possible to model two types of customers: the ones who rejects a particular sensory zone (sugar loaf to the bottom) and the ones who are very satisfied by a particular sensory zone (sugar loaf to the top).

3. **The elliptic model**: a_5 is null. A minimum of 6 products is required. The elliptic model makes it possible to determine one or two zones of maximum preference on one axis of the PCA, in opposition to simpler models which makes it possible to define only one zone preferably maximum per customer. This model also makes it possible to model customers who like products opposed on a sensory dimension i.e. on one axis of the PCA (model in the shape of horse saddle). It does not take into account the interactions between the two axes of the PCA.

4. **The quadratic model** introduced in Sensory Science by Danzart [[10], [11]] corresponds to the complete equation. It is necessary that at least seven products are evaluated. The quadratic model requires the evaluation of more products than the other models but it has an unquestionable advantage: it takes into account the interactions between axis 1 and 2. Thus, it is possible to model a customer who has two areas of maximal preferences in opposition on the map and not only in opposition for a single axis.

The quality of the model, whatever it is, for a given customer is measured by a coefficient of determination.

To summarize information resulting from the modeling of all the customers, it is possible to sum binary functions resulting from the modeling of each customer:

$$\text{Pref } (x_1, x_2) = \sum_{i=1}^{n} C_i(x_1, x_2)$$

where $C_i(x_1,x_2)=1$ if $F_i(x_1,x_2)\geq 0$ and $C_i(x_1,x_2)=0$ if $F_i(x_1,x_2)<0$; $F_i(x_1,x_2)$ is the estimated normalized preference score for the product with (x_1,x_2) coordinates on the PCA, n is the number of customers.

This sum divided by the number of modeled customers and multiplied by 100 leads to a 3D graph of Pref (x_1,x_2), the preferences of the customers (Figure 3 on the left) and a map with the level lines corresponding to this surface (Figure 3 on the right).

For example, on this preference mapping, if a product is located in an area with a level of 70, it means that 70% of the customers should consider this product as good as the average product of the genuine set of products or even better.

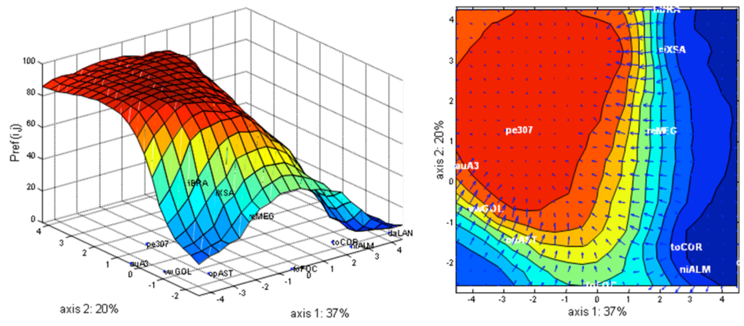

Figure 3: Representation of the sum of the individual models

3. THE CASE STUDY ON STATIC COMFORT

3.1. The Seats and their technical caracterization

The seats used in this study have been chosen to represent a wide panel of comfort. They are from different platforms and different years of origin (Table 1). To maintain confidentiality of the results, seats are represented by a random letter in graphics.

Table 1: Seats evaluated during the study

Seats	Year	Platform
Renault Safrane	1992	H1-segment
BMW 328 i	1998	D-segment
Audi A2	1999	A-segment
Renault Scenic 2	2002	C-segment
Volkswagen Golf	2003	C-segment
Renault Logan	2004	B-segment
Peugeot 407	2004	D-segment
Renault Clio 3	2005	B-segment

A seat can be characterized in many ways: by geometrical characteristics, pressure measures, sensory evaluations and hedonic scores, for example (Figure 4).

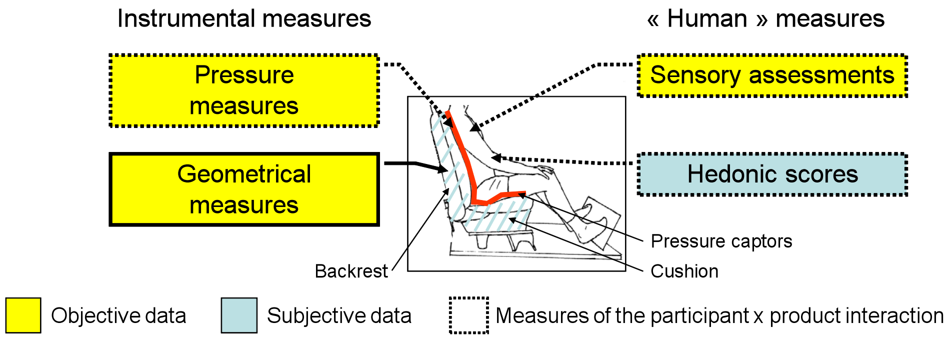

Figure 4: Different types of measures on the seat

The geometrical characteristics are quite easy to apprehend: width and length of the cushion and the backrest, distance between the backrest lateral bolsters…

The pressure measures are much more complicated: the pressure of the customers' body on the seat is measured by a captor containing thousand individual cells taking 100 measures per second. These pressure measurements are quite original because they do not characterize the seat itself like geometrical ones but the interaction of the seat with the participant, like sensory ones. Criteria have to be found to transform these pressure measures into parameters.

3.2. The customer study

The two-hour session had up of several stages. The customer has to adjust all the seats, once and for all to be in a comfortable position. Then he is asked to sit on all the seats as a warm-up to estimate their differences. At last, he tests and scores each seat (from 0 – I don't like this seat to 10 – I like it very much) and writes down his/her remarks on each seat. The order of evaluation follows a Latin square. The seats were presented in circle and were covered with a black sheet to remain anonymous (Figure 5)

Figure 5: The seats during customer study

120 Renault employees took part in the study. They have been chosen to be representative of the European population in 2015: there are 5 distinct anthropometric groups of 24 participants. Their job is also not related to seats conception.

There is a seat effect on the hedonic scores ($F= 27.5$, $p<0.001$): the participants do not like the seats the same way: HHH, FFF & DDD are preferred whereas BBB & AAA have the lowest scores (Figure 6).

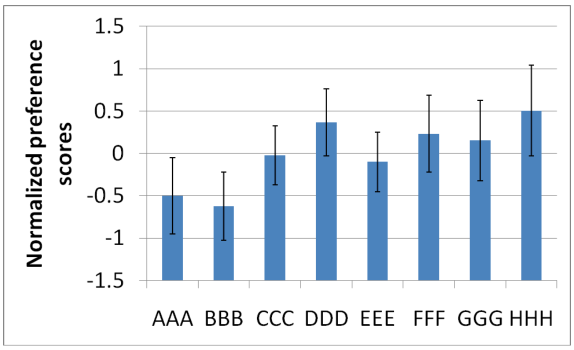

Figure 6: Preference scores of the seats

In this case study, we are interested in technical measures rather than sensory ones. We want to highlight the seat physical properties that lead to get a comfortable feeling. Therefore, our preference mapping is based on pressure maps data and the preference scores. DDD is lying on the [70;75%[area: between 70 and 75% of the customers consider that this seat is above the average. This seat is appreciated for its high values of Weight 2 and Weight 3 (Figure 7).

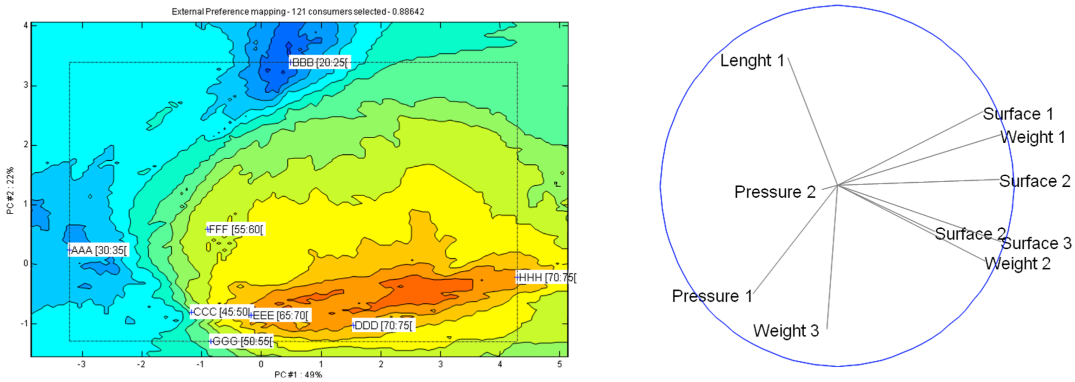

Figure 7: Preference mapping of the seats

4. IMPROVMENTS PROPOSED WITH CARTOPTI

Even if Prefmap is a powerful technique, it could be useless if it was not adapted to industrial problems and if one need to be a Matlab® expert to operate it. That is why we proposed several enhancements of the method and developed a tool useable by everybody.

4.1. Positioning new seats on the preference mapping

To limit the number of customers' studies, we need to be able to estimate the preference scores of a seat according to the technical measures at our disposal. These can be measures of a seat from a competitor or from one of our future seat that we want to evaluate, even if have only a virtual mock-up.

This can be easily achieved by considering the seat to characterize as a supplementary row. With the coordinates of the supplementary row (x_1,x_2), we can calculate Pref(x_1,x_2) (Figure 8).

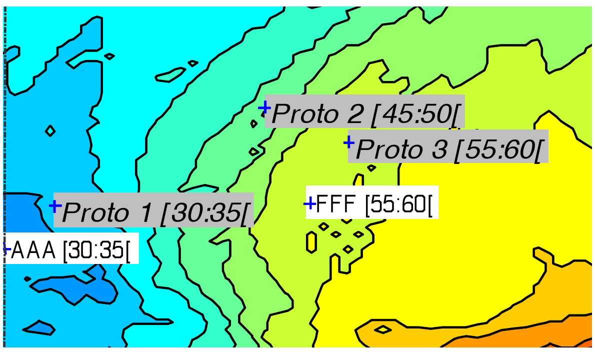

Figure 8: Preference scores of three virtual seat prototypes (Proto1, Proto2 and Proto3)

4.2. Finding the "optimal" product

It is important to estimate the values of the technical parameters for the "optimal" product to define a target for the seat conception. The coordinates of the optimal product can be calculated as the linear combination of the coordinates of real evaluated products. Assuming that this is the same for the sensory scores with the same formula, we can estimate the values of the technical parameters of this optimal product. We have :

1. to find the « higher » point on the map (***O*** on the Figure 9),
2. to find the three surrounding products of ***O*** on the map : ***A***, ***B*** and ***C***,
3. to find *a*, *b* and *c* defining ***O*** as the barycenter of { (***A***,*a*) (***B***,*b*) (***C***,*c*) } with *a*+*b*+*c* =1
4. and to calculate the technical values using the same linear combination.

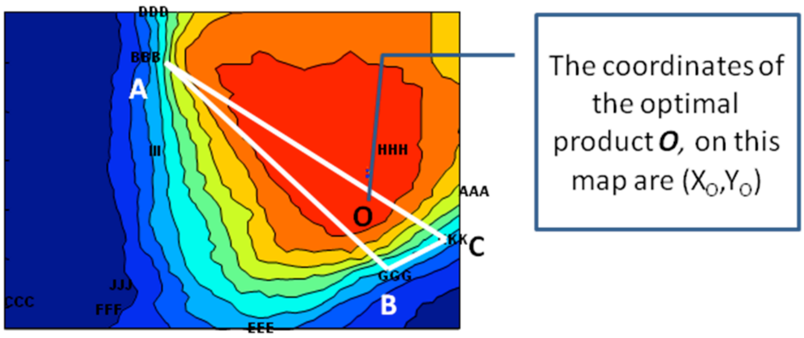

Figure 9: Finding the "optimal product on the preference mapping [[12]]

4.3. Identifying the necessary evolutions from a real product to the "optimal" product

Identifying the optimal product is helping seat experts to design more comfortable seats but they asked for a pathway from their original product to the "optimal" one. Rules of Three of technical values of the two seats, for example from FFF to the optimal product, can easily solve this issue (Figure 10).

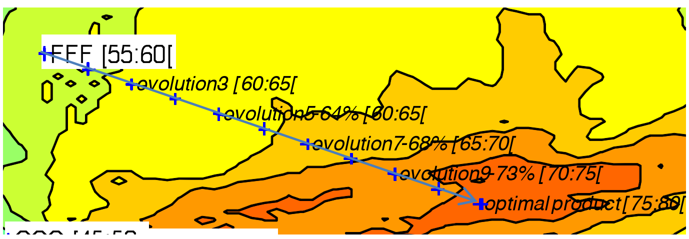

Figure 10: Samples of the pathway from the original seat to the optimal one

4.4. Finding the "optimal" product taking into account that some variables are "fixed"

Finding an "optimal" product is a good option for the future but it is not always realistic. Indeed, from one generation of seats to another, it is quite impossible to begin from scratch, because it would be too expensive. Therefore, we had to re-think the optimal product problem. Generally, some values of the technical data of a seat can be modified. We should consider that some technical parameters are “fixed”: their values cannot change whereas some parameters can vary. Our proposal is based on factorial design matrix.

Using two-level full-factorial design matrix, we “construct” new products (Figure 11). These products are considered as supplementary rows for the PCA. The area defined by these products on the PCA plane is the area of possible modifications of the seat (CCC on the example of Figure 12). All we need to do is to find the optimal point in this area.

Variables	Values
Var1	fixed
Var2	fixed
Var3	min3 - max3
Var4	min4 - max4
Var5	fixed
Var6	min6 - max6
Var7	fixed
Var8	fixed
Var9	fixed
Var10	min10 - max10

Two-level full Fractional design matrix

	Var1	Var2	Var3	Var4	Var5	Var6	Var7	Var8	Var9	Var10
P1	fixed	fixed	min3	min4	fixed	min6	fixed	fixed	fixed	min10
P2	fixed	fixed	min3	min4	fixed	min6	fixed	fixed	fixed	max10
P3	fixed	fixed	min3	min4	fixed	max6	fixed	fixed	fixed	min10
P4	fixed	fixed	min3	min4	fixed	max6	fixed	fixed	fixed	max10
P5	fixed	fixed	min3	max4	fixed	min6	fixed	fixed	fixed	min10
P6	fixed	fixed	min3	max4	fixed	min6	fixed	fixed	fixed	max10
P7	fixed	fixed	min3	max4	fixed	max6	fixed	fixed	fixed	min10
P8	fixed	fixed	min3	max4	fixed	max6	fixed	fixed	fixed	max10
P9	fixed	fixed	max3	min4	fixed	min6	fixed	fixed	fixed	min10
P10	fixed	fixed	max3	min4	fixed	min6	fixed	fixed	fixed	max10
P11	fixed	fixed	max3	min4	fixed	max6	fixed	fixed	fixed	min10
P12	fixed	fixed	max3	min4	fixed	max6	fixed	fixed	fixed	max10
P13	fixed	fixed	max3	max4	fixed	min6	fixed	fixed	fixed	min10
P14	fixed	fixed	max3	max4	fixed	min6	fixed	fixed	fixed	max10
P15	fixed	fixed	max3	max4	fixed	max6	fixed	fixed	fixed	min10
P16	fixed	fixed	max3	max4	fixed	max6	fixed	fixed	fixed	max10

Figure 11: Example of two-level full-factorial design matrix

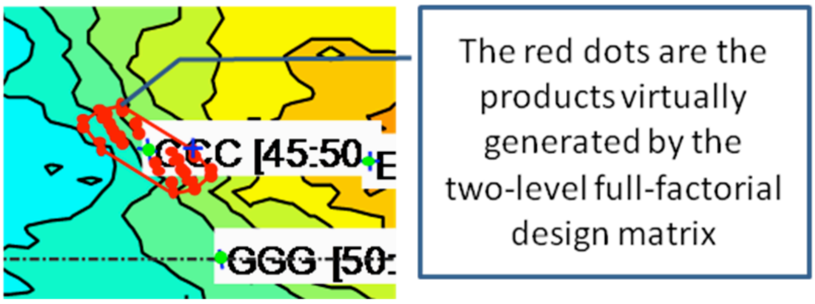

Figure 12: Example of area of “constructed” new products

5. CONCLUSION & PERSPECTIVES

Cartopti is developed under Matlab®. It is an executable program that integrates Prefmap and all the improvements described in this paper (Figure 13).

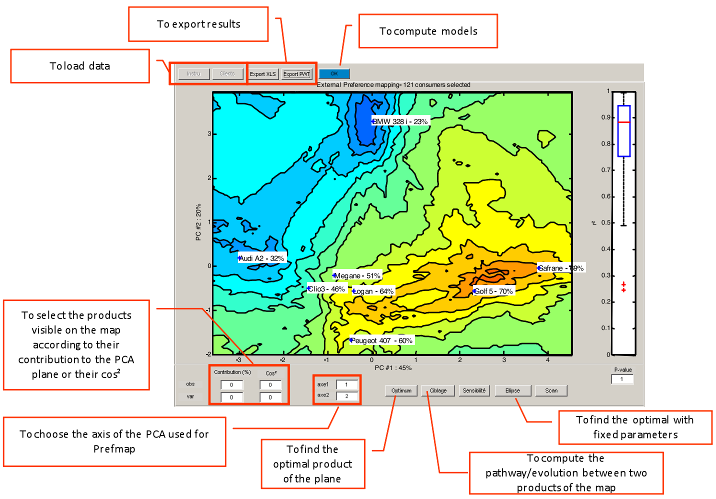

Figure 13: Cartopti screenshot

External preference mapping is a great tool to help seat designers. But the more they use it, the more we will have to adapt and to enhance this methodology. Our next challenge will be to find a way:

- To sort out measures according to their influence on the customers' perception, in order to construct the first plane of the PCA only with the variables required to understand customers' perception.
- To combine several preference mappings provided by several instrumental measures when it has no sense to compute a global PCA with all the data.
- To take into account the cost of the products: we want to be able to evaluate the trade-off between the cost of the seat and the customers' preferences.

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