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AHPSort-GAIA: a visualisation tool for the sorting of alternative in AHP portrayed through a case in the Food and Drink industry

Alessio Ishizaka, Vijay Pereira, Sajid Siraj

NEOMA Business School, 1 Rue du Maréchal Juin, 76130 Mont-Saint-Aignan, France, email : Alessio.Ishizaka@neoma-bs.fr
NEOMA Business School, 1 Rue du Maréchal Juin, 76130 Mont-Saint-Aignan, France, email Vijay.Pereira@neoma-bs.fr
Centre for Decision Research, Leeds University Business School, Leeds, United Kingdom s.siraj@leeds.ac.uk

Abstract

Although Multi-Criteria Decision Making methods have been extensively used for choice problems, their descriptive use has rarely been considered. The descriptive component is important because it allows decision makers to better understand the problem. In this paper, we add the descriptive method GAIA as an extension to the AHPSort method that helps policy makers to gain insights into their decision problems, through the portraying of a case in the food and drink industry. This descriptive component is implemented as a visual analysis. The proposed extension has been implemented in an open-source software tool that allows users to visualise the different performances of food suppliers within a review process and provide feedback for improvements within the food and drink industry.

Keywords: AHPSort, GAIA, visualisation, sorting, food industry

1. Introduction

Taking right decisions is of paramount importance. However, decisions are often of conflicting multicriteria nature. Therefore, taking decision is not trivial. To help in this exercise, several multicriteria decision making techniques have been developed (Ishizaka and Nemery 2013). These techniques are mainly designed for choice or ranking problems. Choice problems encompass those problems where you need to select only one of the alternatives. Ranking problems order the alternatives from the best to the worst, while in a sorting problem, alternatives are assigned to predefined ordered classes.

UTADIS (Jacquet-Lagrèze and Siskos 1982) was the first method developed for sorting problems. Recently, sorting methods has boomed with ELECTRE-Tri (Yu 1992), Electre Tri-C (Almeida-Dias et al. 2010), ELECTRE-SORT (Ishizaka and Nemery 2014), ELECTRE Tri-nC (Almeida-Dias et al. 2012), ELECTRE Tri-nB (Fernández et al. 2017), TOPSIS-Sort (Sabokbar et al. 2016; de Lima Silva and de Almeida Filho 2020), VIKORSORT (Demir et al. 2018), MACBETHSort (Ishizaka and Gordon 2017), DEASORT (Ishizaka et al. 2018), AHPSort (Ishizaka et al. 2012), GAHPSort (López and Ishizaka 2017), Cost-Benefit AHPSort (Ishizaka and López 2019), Fuzzy-AHPSort (Krejčí and Ishizaka 2018) and AHP-Fuzzy Sorting (Ishizaka et al. 2020). In order to explain the results to the decision-maker, GAIA (Brans and Mareschal 1994) has been coupled with FlowSort (Nemery et al. 2012). In this paper, we also coupled for the first time this descriptive technique with AHPSort.

The GAIA-AHPSort hybrid technique will be used to evaluate food and equipment suppliers for a restaurant in the food and drink industry. We respond specifically to the special issue call on research within this important industry by portraying a case study within the United Kingdom restaurant (food and drink) industry. We argue that as the quality of the restaurant depends not only of the internal staff and process but also of the suppliers, it is important to sort them into classes of performances and provide them feed-back on how to improve. Our study thus contributes in several ways overall to the call for papers. More specifically this paper contributes by investigating the risk, uncertainties, cost efficiency, and resiliency in food and drink supply chain / logistics networks within the booming UK restaurant (food and drink) industry. We identify that although Multi-Criteria Decision Making methods have been extensively used for choice problems, their descriptive use has rarely been considered. We thus argue that the descriptive component is important because it allows decision makers to better understand the problem. Thus, our key contribution in this paper, is where we add the descriptive method GAIA as an extension to the AHPSort method that helps managers and policy makers in the restaurant (food and drink) industry to gain insights into their decision problems. In doing so we use hybrid visual analytical tools through visual presentations in our study, as this has many future applications as it can help managers to establish more informed, consensual and improved complex performance evaluation.

The rest of the paper is constructed as following. Section 2 review the literature in the performance evaluation in the food industry. Section 3 presents the new hybrid methodology. Section 4 describes the case study and section 5 concludes the paper.

2. Literature review

Modern day businesses rely on their strategic partnerships, such as suppliers. The success, reputation and sustainability of organisations within the hospitality industry, including restaurants are no different. Thus, the choice of a supplier in the context of supply and purchasing is extremely important when it comes to restaurant operations, and this has been acknowledged as being a key factor for the survival of the restaurant industry (see for e.g., arguments made by (Cho et al. 2019). Very early on there was a seminal piece by Gee (1975), who identified supplier decision aspects within a restaurant business, such as avoiding shortage of raw-material of food stocks and ingredients, planning on a daily, weekly, fortnightly and monthly basis for e.g., taking into account price fluctuations, speed at which orders and deliveries can be supplied, keeping on top of its various inventories, quality control, unpredictable competition and cycles and fluctuations of demand and supply. The restaurant business also faces further challenges in terms of demands by both customers and the dishes they have to serve, and hence need to develop strategic marketing and sales plans in order to both retain existing customers, but also to overcome competition and attain a competitive advantage (see recent work by (Cho et al. 2016).

It is therefore paramount for restaurants to be strategic when it comes to identifying challenges, in the context of purchasing decisions to be successful. For the purposes of this study, we scan the extant literature and identify eight variables that are important to base a decision of choosing a supplier and being successful in that partnership. These are quality (better and higher); cost (as compared to competitors); delivery time (speed of supplies being delivered); flexibility (depending on the order being small or big quantity); line of credit (greater time period versus lower); range of products (including perishable (e.g. meat, fruits, vegetables, etc.) and non-perishables (e.g. tissues, kitchen roll, tin food, etc.); geographical distance of the supplier to business (to meet, see the products and negotiate); and relationship (less versus more number of conflicts). The choice for these are justified through the literature below.

Acquiring quality and fresh raw-material (both perishable and non-perishable) is crucial when it comes to sustaining a restaurants core competencies and to continuously improve quality (e.g. Pun 2001). Customers frequenting restaurants are very fickle minded and may let go of their custom and go elsewhere (Gilbert 2004), and further, attracting new customers in the restaurant business is more expensive than retaining existing ones (Szmigin 1998). Maintaining quality goes hand in hand with the prices the restaurant owners charge for their finished products, which in turn is related to the prices of the raw-material they acquire. Research provides evidence that the cost/value was one a key determinant when it came to predicting repeat customers (e.g. Ribeiro Soriano 2002). Further, there has been a substantial increase in maintaining a restaurant, with high overhead costs. Such as rent, electricity, water, salaries, music licenses, municipality charges etc., to name a few. Hence, to maintain lower costs of finished products, restaurant owners are looking for suppliers with lower costs (Cousins and Menguc 2006). Alongside quality and cost, delivery time i.e., speed of supplies being delivered, is also crucial factor in deciding a supplier (Carr and Smeltzer 2000; Perols et al. 2013). Timing becomes crucial is the restaurant business as it deals with customers that are very volatile and demanding. The next variable, 'flexibility' i.e., the willingness or unwillingness of a supplier to be flexible depending on how small or big the order is being placed on the quantity required is also key when a supplier choice is made (Cho et al. 2016). Similarly, a decision on choice of a supplier becomes extremely important in the restaurant business, as in any other business, where the line of credit is flexible and deeper as well as longer i.e. larger amounts for longer periods (e.g. Anderson and Juma 2011). The availability of a range of products under one roof, is also an important variable when restaurateurs make a decision in choosing a supplier (Murphy and Smith 2009). Similarly, geographical distance, of the supplier to business is an important determinant when it comes to choose a supplier, as it is important to physically meet, see the products and negotiate the quality, cost, timing etc., when ordering or purchasing (Duram and Cawley 2012; Autry et al. 2014). Last, but not the least, the importance of relationship is a key determinant when it comes to choosing a supplier (Shi and Liao 2013; Lockshin et al. 2011).

3. Methodology

This hybrid method is based on the sorting methods AHPSort (Ishizaka et al. 2012) and GAIA (Brans and Mareschal 1994).

3.1. AHPSort

AHPSort is based on eight steps:

A) Problem definition

1) Define the goal, criteria c_j, $j = 1,\ldots, m$ and alternatives a_k k = 1,…, l of the problem.

2) Define the classes $C_i, i=1,\ldots,n$, where n is the number of classes. The classes can be ordered and have a label (e.g. excellent, good, medium, bad)

3) Define the profiles of each class. This can be done with local limiting profiles lp_{ij}, which

indicates the minimum performance needed on each criterion j to belong to a class C_i.

B) Evaluations

4) Perform a pair-wise evaluation on the importance of the criteria c_j and derive their weight w_j with the eigenvalue method of the AHP.

$$\mathbf{W} \cdot \mathbf{w} = \lambda \cdot \mathbf{w} \tag{2}$$

Where **W** is the comparison matrix of weights,

w is the weight vector,

λ is the maximal eigenvalue

5) Compare the alternative a_k and the limiting profiles lp_{ij} for each criterion j. Enter the comparisons in the matrix $\mathbf{A_j}$. Only the upper or lower part of the matrix needs to be completed as the matrix is reciprocal.

$$\mathbf{A_j} = \begin{bmatrix} \frac{a_k}{a_k} & \frac{a_k}{l_{1j}} & \cdots & \frac{a_k}{l_{mj}} \\ \frac{l_{1j}}{a_k} & \frac{l_{1j}}{l_{1j}} & \cdots & \frac{l_{1j}}{l_{mj}} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{l_{mj}}{a_k} & \frac{l_{mj}}{l_{1j}} & \cdots & \frac{l_{mj}}{l_{mj}} \end{bmatrix} \tag{3}$$

6) From the comparison matrices, derive the local priority p_{kj} for the alternative a_k and the local priority p_{ij} of the limiting profiles lp_{ij} with the eigenvalue method

$$\mathbf{A_j} \cdot \mathbf{p} = \lambda \cdot \mathbf{p} \tag{4}$$

Where $\mathbf{A}_j$ is the comparison matrix of one alternative and the limiting profiles

p is the priority vector

C) Assignment to classes

7) Aggregate the weighted local priorities, which provide a global priority p_k for the alternative k (5) and a global priority lp_i for the limiting profile (6).

$$p_k = \sum_{k=0}^{m} p_{kj} \cdot w_j \tag{5}$$

$$lp_i = \sum_{j=1}^{m} lp_{ij} \cdot w_j \tag{6}$$

The comparison of p_k with lp_i is used to assign the alternative a_k to a class C_i (7). The alternative a_k is assigned to the class C_i, which has the lp_i just below the global priority p_k (Figure 1).

$$p_k \geq lp_1 \quad \Rightarrow \quad a_k \in C_1$$

$$lp_2 \leq p_k < lp_1 \quad \Rightarrow \quad a_k \in C_2 \tag{7}$$

$$\ldots$$

$$p_k < lp_{n-1} \quad \Rightarrow \quad a_k \in C_n$$

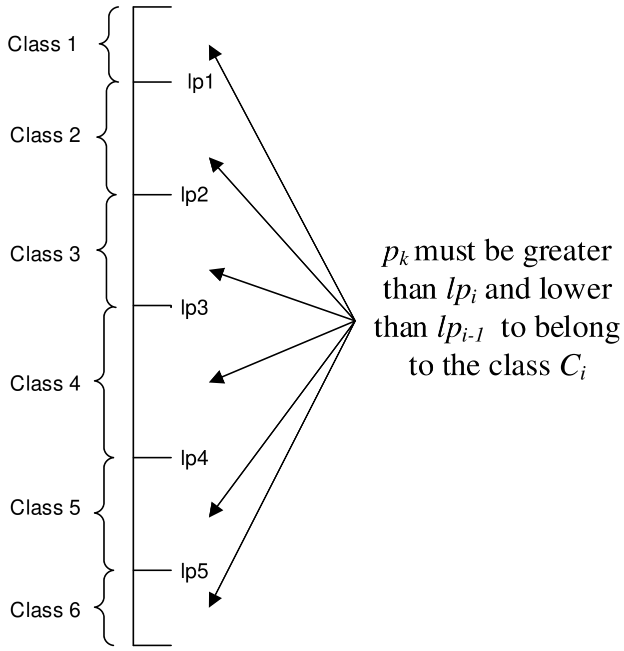

Figure 1 Assignment

8) Repeat processes 5) to 8) for each alternative to be classified.

If the decision-maker is unable to provide a limiting profile, AHPSort can also be used with a central profile, which corresponds to a typical example of the class. However, this version is less accurate (Ishizaka et al. 2012).

3.2. AHPSort-GAIA – A visualization aid for AHPSort

3.2.1. Calculating AHPSort-GAIA

The application of statistics and machine learning methods to MCDA techniques is an old research trend that recently became quite popular. For example, recently a linear optimisation model (Lolli et al. 2019) and a logistic regression method (Balugani et al. 2020) have been used to infer criteria weights from examples for the MCDA method PROMETHEE. In this paper, GAIA uses the principal component analysis technique from statistics to reduce the dimensionality. It is a widely applied technique to find and sort axes of maximal variance. The idea of GAIA is to represent multidimensional information in a low dimensional space with as much information as possible. For example, a decision problem that involves six criteria will have six-dimensional scores assigned to each alternative, which is impossible to visualize in a conventional Euclidean space. This is sometimes referred to as "curse of dimensionality".

Consider the priority decision matrix M with l alternatives $(a_k|\ i = 1,2,\dots,l\ )$ and m criteria $(c_j|\ j = 1, 2, \dots, m\ )$, where s_{ij} is the local priority of alternative k on criterion j:

$$\mathrm{M}_{k\times j} = \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1j} & \cdots & s_{1m} \\ s_{21} & s_{22} & \cdots & s_{2j} & \cdots & s_{2m} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ s_{k1} & s_{k2} & \cdots & s_{kj} & \cdots & s_{km} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ s_{l1} & s_{l2} & \cdots & s_{lj} & \cdots & s_{lm} \end{bmatrix} \tag{8}$$

This matrix has the property to be unit less due to the fact that the local priorities are calculated from comparisons of pair-wise ratios. The priorities of the alternatives are calculated separately in AHPSort. For each alternative, a different matrix $\mathrm{A_j}$ (3) is filled. To connect the priorities calculated for each $\mathrm{A_j}$ and make them comparable, we need to rescale them with two linking pins. These two linking pins are two identical objects that are present in each $\mathrm{A_j}$, in our case, the two limiting profiles. The rescaling formula is given by:

$$z = \frac{x - linking\ pin\ 1}{linking\ pin\ 2 - linking\ pin\ 1} \tag{9}$$

These ratio values must be log-transformed in order to have a symmetric distribution of values. For example, consider a situation where one alternative is considered 4 times better than the limiting profile and another one is considered 4 times worse than the limiting profile. The two alternatives clearly have equal distance from the limiting profile but the ratio scale produces skewed results, i.e. the first alternative has a distance of ¾ (= 1 - ¼) units while the second one has a distance of 3 units (= 4 – 1). This anomaly can be avoided simply by taking log transformations into consideration. As the ideal normalisation is used, a log-normal transformation is required.

As the data are unit less and comparable, they can be represented in an m-dimensional space. Each dimension in this space represents one of the m criteria. The l alternatives are located in this space according to their relative local priority calculated on each criterion.

In order to map the decision table on two principal components, we compute the co-variance matrix C,

$$C = \mathrm{M}^{\mathrm{T}}\mathrm{M}, \tag{10}$$

where M^{T} denotes the transposition of M.

The eigenvalues $\lambda_j (j = 1, \dots n)$ of C represent the amount of information contained in each principal component and their respective eigenvectors represent the direction of the principal component.

The two eigenvectors u and v with the highest eigenvalues correspond to the first two principal components. The coordinates of each alternative i in the (u, v) plane are given by

$$(u_i, v_i) = \left(M_i^{\ T} * u, M_i^{\ T} * v\right), \tag{11}$$

where M_i is the i^th^ row of M.

As the criteria were represented along each axis in the original space, their translation in the (u, v) plane represents the strength on each criterion. This can be calculated as the projection of the original axes on the (u, v) plane, i.e.

$$(e_k{}^T u \, , e_k{}^T v), \tag{12}$$

where e_k is the unit vector direction of the j^th^ criterion in the original space.

The overall preference direction can also be calculated in a similar fashion by taking projection of the original weight vector on the (u, v) plane, i.e. $(w^T u \, , w^T v)$, where w is the weight vector given to the criteria. This is also known as the decision stick in the PROMETHEE context.

In the projection, some information is lost. The amount of preserved information is calculated with:

$$\delta = \frac{\lambda_1 + \lambda_2}{\sum_{j=1}^{q} \lambda_j} \tag{13}$$

where λ_1 and λ_2 are the highest two principal eigenvalues.

The extension of GAIA for AHPSort has been programmed and tested in PriEsT (Siraj et al. 2013), which is an open source software tool available online.

3.2.2. Interpreting the AHPSort-GAIA plane

An illustrative example of a GAIA plane is given in Figure 2, where the criteria are represented by four vectors (see arrows c1, c2, c3, and c4 emanating from centre) and the alternatives are represented by dots. The decision stick (labelled as DS) represents the preferred decision direction when taking into account all criteria. The reading is done by projection on the relevant arrow. For example, we can notice by the projection of DS, that alternative a3 is the preferred alternative. For c3, alternative a5 is the best.

An angle between two vectors represents the degree of correlation between two criteria, i.e. the smaller the angle between two arrows, the similar these criteria are. For example, c1 and c4 in Figure 2 have similar preferences but c1 and c3 have almost opposite (conflicting) preferences. Finally, if alternatives are close, it means that they are similarly ranked on all criteria (e.g. a1 and a6).

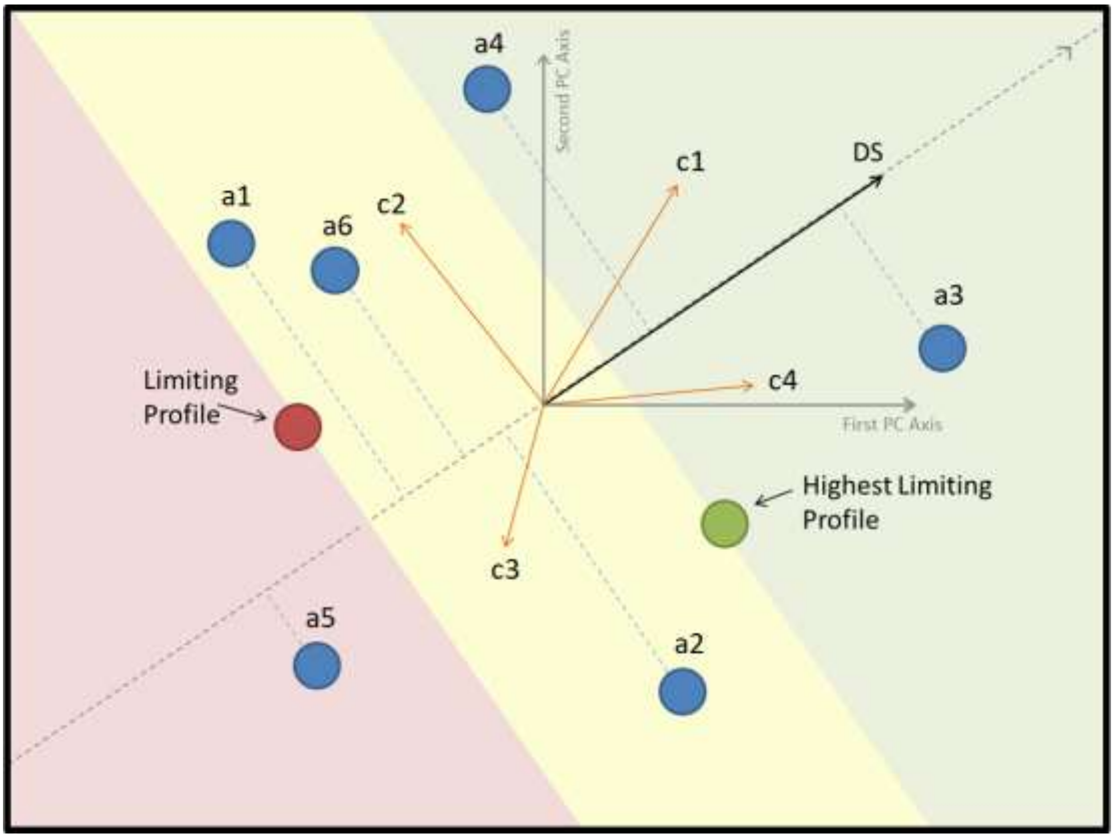

Figure 2: Example AHPSort-GAIA graph. The horizontal and vertical axes represent the first principal component (PC) and the second PC of the information table, respectively.

The limiting profiles can be seen as dots just like other alternatives, however these limiting profiles can be used to define the boundaries on the decision stick (DS) – as shown in the figure. The highest limiting profile is marked in the figure near the centre right position, which declares the alternatives a3 and a4 to be members of the most preferred class. Similarly, the other limiting profile (shown near the centre-left position) declares a5 to be a member of the least preferred class. The remaining alternatives are therefore members of the intermediate class. As described earlier, there are $n-1$ limiting profiles required for defining n classes, therefore, we have two limiting profiles in Figure 2 that define three classes.

4. Case study

4.1. Background

The restaurant industry in the United Kingdom has in the last decade (2008-2018) seen a phenomenal growth. The extent people in the UK spend on restaurants and cafes in 2017 was 88 billion GBP (Statista 2018). To cater to this massive demand, the number of restaurants have been progressively increasing, financially leading to a contribution of 17.9 GBP to the non-financial business economy. The Statista Research Department, 2018 report quotes the consulting firm Deloitte that estimated the financial turnover for the restaurant industry in the

UK to be 29.3 billion British pounds in 2014. The same report states that on an average a UK household spent 19 GBP a week on restaurants and cafés, the figure being even higher for those in the age-group of 30 to 64. Though US fast food giants McDonalds, KFC and are the most popular with UK restaurant and cafe consumers, 'other' smaller, local, regional individually owned restaurant and cafés chains and outlets are also very popular. Additionally, there are many British Pubs, Indian, Chinese, Italian, French and global food outlets that include the mix in the UK restaurant industry. Further these 'other' restaurants and cafés could be classified as high end, medium and low.

Our case study is one such individually owned Indian restaurant in Southampton, UK. It is an 80 seater high-end restaurant, that serves lunch and dinner. The opening timings are 12am-3pm and 6pm-1am. We interviewed the 2 owners, managers and chefs to gather detailed information about the restaurant and more particularly about their purchasing planning and strategy. The restaurant focused highly on quality, hygiene and customer service. They hired three chefs, two helpers in the kitchen, five waiters, a full time cleaner and a manager. They had diverse suppliers for different things, linen was for example from a supplier, whereas the meat and fish supplier was different, fresh food like vegetables, fruit and dairy was different, raw materials such as spices, oil etc., were procured from different suppliers. The key conditions where they chose or used a supplier was when and where they got better value. The planning, costing and quantity requirement was done by the owners in consultation with the two main chefs. We were told that the restaurant changed the supplier a few times because they found that it did not suit them in terms of quality, cost and consistency. To classify and give recommendations to the supplier of the restaurant, we use the methodology described in section 3.

4.2. Problem definition

The first step is to define the problem. We did it with the owners of the restaurant. Eight suppliers were identified:

A) Beverage (Alcohol & soft drinks)
B) Meat
C) Vegetables
D) Spice
E) Desserts
F) Laundry
G) Napkins & Cutlery
H) Cleaning products

The goal is to classify them into three classes: good, medium (we retain the supplier but improvements are required), bad (we replace the supplier). Eight criteria has been retained in accordance to the literature review in section 2 and the consultation with the restaurant manager. For each criteria, two limiting thresholds defining the three classes have been set (Table 1).

	Threshold good	Threshold medium
Quality (rejection)	maximum of 2 item rejections	maximum of 4 item rejections
Cost	10% cheaper than the average price on the market	average price on the market
Delivery time	same day	1 day
Flexibility (I can order small or big quantity)	can accept an increase or decrease of 50% than average order	can accept an increase or decrease of 25% than average order
Line of credit	30 days	7 days
Range of products (including perishable (meat, fruits, vegetables) and non perishables (tissues, kitchen roll, tin food, etc))	50 products	25 products
Geographical distance supplier to business (to meet, see the products and negotiate)	10 km	25 km
Relationship (number of conflicts)	0	2 per year

Table 1: Criteria and limiting thresholds

4.3. Evaluation

The second step was to evaluate the importance of each criteria. The manager filled a pairwise comparison questionnaire (Table 2). For example, the first line of Table 2, the decision-maker evaluates Quality 4 times more important than Cost. Using (2), the derived weights are given in Table 3. Quality and costs are the two most important criteria. Together they count more than 50% of the weight.

Quality	4	>	Cost
Quality	5	>	Delivery time
Quality	6	>	Flexibility
Quality	4	>	Line of credit
Quality	5	>	Range of products
Quality	5	>	Geographical distance
Quality	4	>	Relationship
Cost	4	>	Delivery time
Cost	4	>	Flexibility
Cost	3	>	Line of credit

Cost	5	>	Range of products
Cost	5	>	Geographical distance
Cost	4	>	Relationship
Delivery time	3	>	Flexibility
Delivery time	1	=	Line of credit
Delivery time	2	>	Range of products
Delivery time	2	>	Geographical distance
Delivery time	2	<	Relationship
Flexibility	3	<	Line of credit
Flexibility	2	<	Range of products
Flexibility	2	<	Geographical distance
Flexibility	3	<	Relationship
Line of credit	3	>	Range of products
Line of credit	4	>	Geographical distance
Line of crédit	3	>	Relationship
Range of products	2	>	Geographical distance
Range of products	2	<	Relationship
Geographical distance	2	<	Relationship

Table 2: Criteria questionnaire

Criteria	**Weights**
Quality	0.366
Cost	0.244
Delivery time	0.077
Flexibility	0.034
Line of credit	0.121
Range of products	0.052
Geographical distance supplier to business	0.042
Relationship	0.083

Table 3: Weight of the criteria

4.4. Assignment to classes

Each supplier is pairwise compared with the thresholds (Table 1). The resulting classification is given in Table 4. Six suppliers are classified as good and two as medium. The next step is to give recommendation to these two supplier on how to improve.

Supplier	Reference Label	Class
Beverage (Alcohol & soft drinks)	A	good
Meat	B	medium
Vegetables	C	medium
Spice	D	good
Desserts	E	good
Laundry	F	good
Napkins & Cutlery	G	good
Cleaning products	H	good

Table 4: Classification of supplier

4.5. Descriptive tool

Although the six suppliers were classified in the previous step, the *AHPSort-GAIA plane* was offered to decision makers in order to help them gain insights into their decision problems. This proposed tool was implemented as an extension for PriEsT (Siraj et al. 2013). The extension allows users to visualise the different performances of food suppliers within a review process in one figure, along with the predefined GOOD and MEDIUM profiles. A screenshot of the suppliers' performance is shown in Figure 3 where Suppliers E, F and H are outperforming other suppliers, while on the other end, Suppliers A, B and C are dominated by all other suppliers. This visual tool also gives us an insight into criteria, for example, we can see that the criteria of Delivery, Quality and Cost are all aligned well, which means that the scores for these criteria are highly correlated. Please note that the labels for Quality and Cost criteria are printed on top of each other by the tool, this is because the two criteria turned out to be extremely close to each other. On the other end, the criteria of Flexibility and Range are also correlated with each other, but they do not align well with the Delivery, Quality and Cost. All other criteria are quite disparate, showing a little or no correlation with others.

This tool was considered very helpful by the decision makers, as it not only explains the best and worst suppliers, it also gives insight towards the nature of the problem. For example, the decision makers realised that although A, B and C had low overall score, they performed very well in the two criteria of flexibility and range. These three suppliers could have got high scores if the decision makers assign high importance to the criteria of flexibility and range.

Another interesting observation is that all the suppliers score quite high as the plot shows that they were considered better than GOOD profile. It is also to note that a two dimensional projection induce some distortions (information content is 81% on Figure 3). Therefore, the suppliers B and C that are borderline classified medium (Table 3), are classified borderline Good on the GAIA plane.

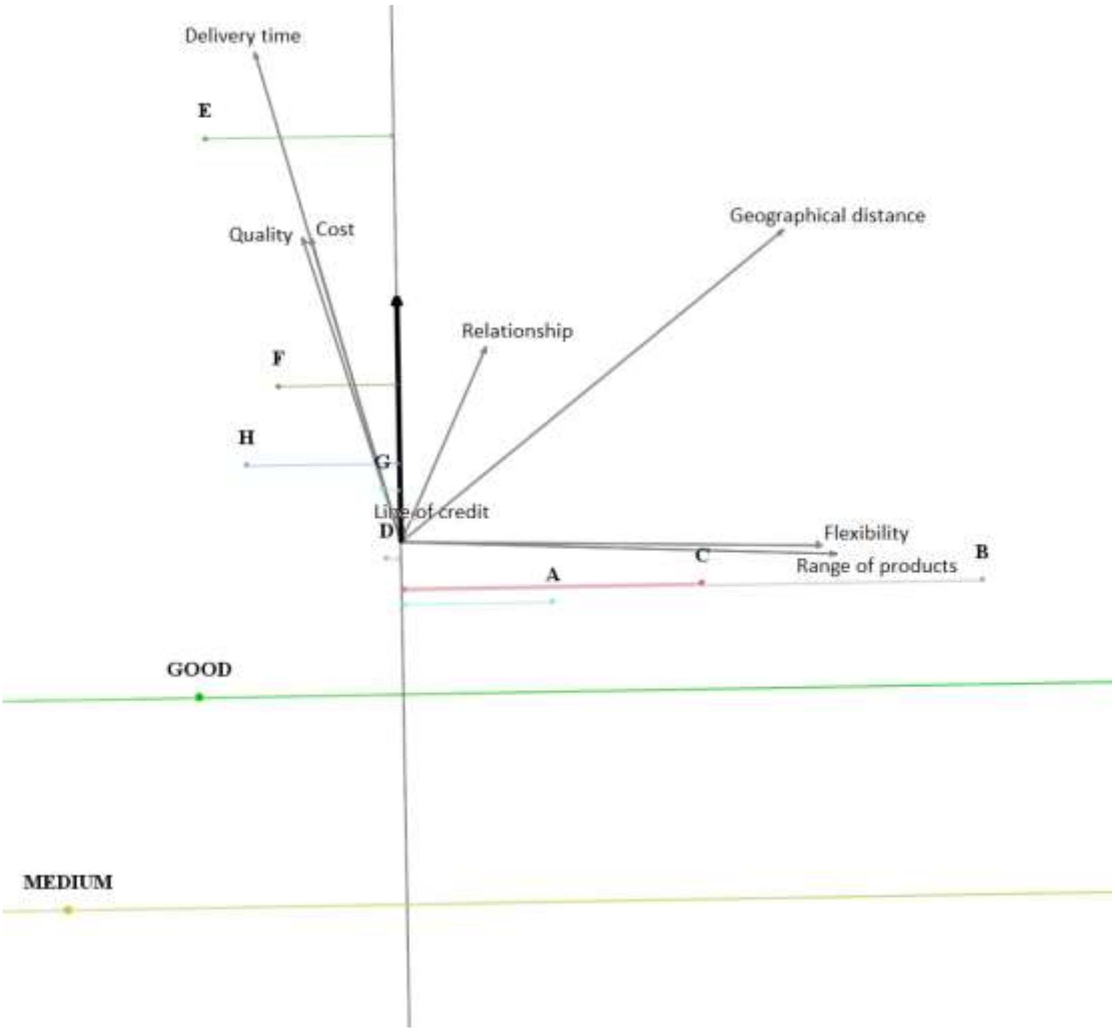

Figure 3: Visualising suppliers' performance on AHPSort-GAIA plane. The labels A to H represent the suppliers mentioned in Table 4.

5. Conclusion

In today's increasingly globalised and complex economy that is flooded with data, taking decisions is a much more complex task. To help managers to tackle this challenge, we have developed a new multi-criteria performance management method that provides input for visual management and continuous improvement initiatives.

To improve, possible corrective strategies need to be identified and discussed. Visual analytical tools offer a way of presenting, justifying and explaining effectively and transparently decisions. Visual representation permits users to take in a large amount of information simultaneously as it maximises human capacity to perceive, understand and reason about complex data and situations. Visual representations promote high-quality human judgement with limited investment of the analysts' time. Visual management has largely been used in production management in the forms of visual stream mapping, flow charts and area name boards. In this paper, we proposed and investigated the use of descriptive tools for gaining insights into decision making problems. The proposed tool was evaluated with the help of a real-world case study, involving the assessment of suppliers. Although the tool was considered useful and interesting, the obvious limitation was its dependence on dimensionality reduction, which in turn, reduces the amount of information visible in this visual tool. Therefore, we recommend interpreting these AHPSort-GAIA plots with care, and it is recommended that the amount of retained information be shown along with these plots (like shown in Figure 3).

The proposed hybrid tool has many future applications as it can help managers to establish more informed, consensual and improved complex performance evaluation. It is also to note that AHPSort-GAIA is generic enough to be used for many decision problems, thus opening up an avenue to a large range of applications.

Finally, GAIA has already been coupled with PROMETHEE (Mareschal and Brans 1988), AHP (Ishizaka et al. 2016) and in this research with AHPSort. This descriptive component can be introduced and investigated for several other MCDM methods, which is an area for future research.

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