American Journal of Science and Technology
2015; 2(5): 251-257
Published online September 10, 2015 (http://www.aascit.org/journal/ajst)
ISSN: 2375-3846

American Association for Science and Technology

Keywords
Decision Making,
Manufacturing Strategy,
Performance,
SMEs,
Visual PROMETHEE

Received: July19, 2015
Revised: August22, 2015
Accepted: August23, 2015

Decision Making Model Based on PROMETHEE for Manufacturing Strategy Direction and Performance Improvement in Manufacturing SMEs

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Citation
Sarkawt Rostam. Decision Making Model Based on PROMETHEE for Manufacturing Strategy Direction and Performance Improvement in Manufacturing SMEs. *American Journal of Science and Technology*. Vol. 2, No. 5, 2015, pp. 251-257.

Abstract
Sustainability in productivity and improvement of manufacturing performance is the essential factor for surviving and growing of small-medium enterprises (SMEs). Due to globalization and rapid technological development, manufacturing companies are in need of revising their manufacturing and production strategy from time to time to improve their performance. So, the need for a decision framework to choose suitable manufacturing strategy direction used in production planning and control in SMEs is crucial. Furthermore, companies are in need of being aware of the key performances that influence their success and growth in the competitive markets by considering the abilities of their production systems. This paper proposes a decision making framework using PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) for SMEs key drivers to improve manufacturing performance and enhance the manufacturing strategy direction for growth, survival, and competition in the market environment. The proposed methodology shows valuable aide to analyze the results.

1. Introduction

It is clear that the role played by small-medium enterprises (SMEs) in the revitalization of the market and therefore boosting the economy is as important as the role of large firms. In addition SME attracts a considerable number of the labour force and help to reduce the unemployment rate.

Due to globalization and technological progress, SMEs need to improve and develop their business environment and manufacturing strategies direction to satisfy the customers' requirements and therefore to be competitive.

The strategic choices of both small and large firms are made basically on the market they serve and they are under the market's competitive forces [1], where the advantage of sustainable competitiveness can be accomplished by proper planning of market orientation directions including factors of innovative practices and long-term survival and growth [2-4].

Nowadays, the SMEs are under the pressure of production systems' flexibility, product quality, innovativeness and competitiveness capabilities. On the other hand, the requirement of product customization and rapid technological changes forced the firms to revise their manufacturing strategies time to time. This strategy has been implemented through the inserting of both advanced manufacturing systems and technologies such as advanced manufacturing technology (AMT), computer integrated manufacturing (CIM) and computer-aided design and manufacturing (CAD/CAM) applications. This leads SMEs to re-engineering their production systems for successful competition [5-6].

For manufacturing SMEs, the process of improving of product development and reducing the product cycle time are considered as essential factors for quick entry to the market. This issue has been addressed successfully by large companies while the SMEs have not paid an appropriate attention to that [7] but they are able to offer customized product with great detail that fits the needs of the customers [8].

In this turbulent environment, for the new market requirements and customer satisfaction that is looking for a product with best quality and least price, it is necessary for SMEs to review their manufacturing systems and re-engineering the production process from time to time to improve the performance of production systems and quality of the products.

The work presented in this paper is an attempt to model a decision making framework to choose the best manufacturing strategy direction used in production planning and control in manufacturing SMEs to improve the performance of their manufacturing systems. The reminder of the paper is structured as follows. Section 2, presents the manufacturing strategy direction in manufacturing SMEs. Section 3 explains the model methodology. This section includes a brief background to PROMETHEE method followed by the detail of the solution methodology. Results and discussions will be presented in Section 4 followed by conclusions and future works in Section 5.

2. Manufacturing Strategy Direction in Manufacturing SMEs

Manufacturing strategy can be defined as a "set of coordinated objectives and action programs applied to a firm's manufacturing function and aimed at securing medium- and long-term, sustainable advantage over that firm's competitors. The manufacturing function requires a strategy to ensure a match, or congruence, between the company's markets and the existing and future abilities of the production system". The manufacturing strategy literature suggests four competitive priorities: cost, quality, delivery, and flexibility [9]. Gerwin [10] elaborated on attributes such as cost, quality, delivery, flexibility and innovation that are termed as competitive priorities or manufacturing performance objectives.

Manufacturing outputs of cost, quality, performance, delivery, flexibility and innovativeness and their measures (Fig.1) were adopted by Leong et al. [11].

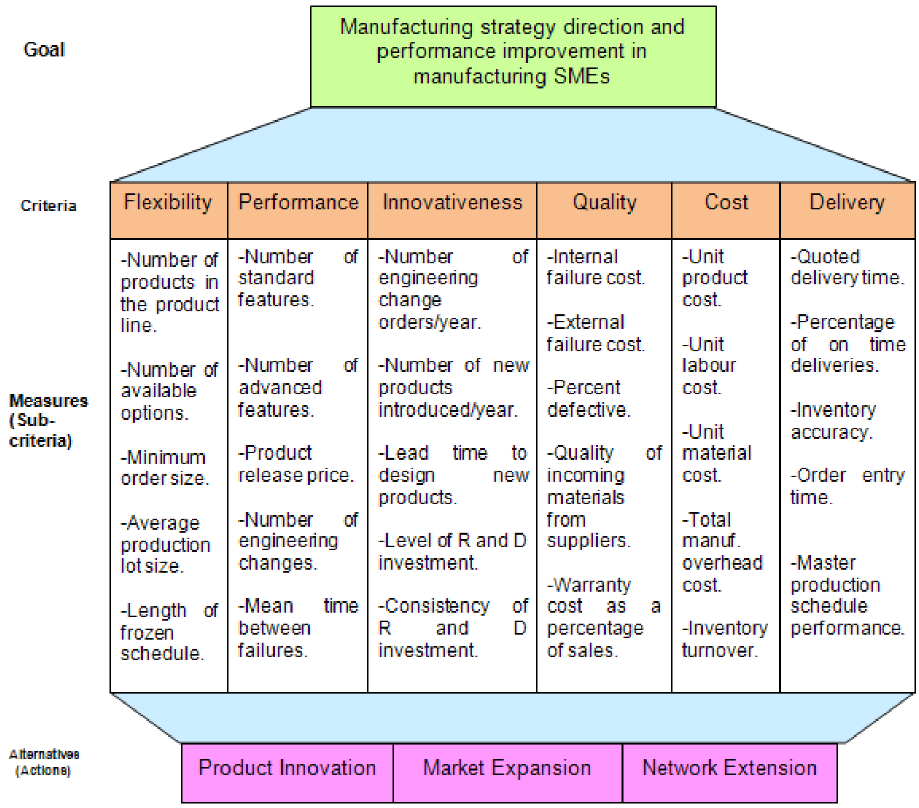


Fig. 1. Proposed Model.

Lin et al. [12] address three critical factors for the success of manufacturing SMEs. These factors are management activities, participation of business partners in relevant decision-making activities and proactive of SMEs with decision-making.

The implementation of manufacturing strategy is not static. It is considered as an ongoing process which acquires management knowledge and collection of market information [13].

The proposed model of manufacturing strategy direction and manufacturing performance improvement in manufacturing SMEs is shown in Fig.1. The criteria, sub-criteria and alternatives are extracted from reviewed literature (e.g. Leong et al.[11]). The hierarchy structure shown in the figure is composed of four levels. At the top of the hierarchy, level 1, the objective of the proposed model has been stated. To achieve this goal both level 2 (criteria, the manufacturing objectives) and level 3 (sub-criteria or measures) are adopted. At the bottom of the hierarchy the alternatives are defined.

3. Model Methodology

3.1. PROMETHEE Method

The PROMETHEE method is considered as one of the most recently developed multiple criteria decision making methods. It is an outranking method for a finite set of alternative actions to be selected and ranked among a set of criteria. The method was developed by Brans and extended by Brans and Vincke [14]. Behzadian et al.[15] present a comprehensive survey of PROMETHEE and its applications in different aspects.

PROMETHEE is based on extensions of the notion of criterion. Six possible extensions (usual criterion, level criterion, U-criterion, V-criterion, criterion with linear preference and indifference area and Gaussian criterion) were used in PROMETHEE and can easily be identified by the decision-maker. This extension gives the preference of the decision-maker for an action *a* with regard to *b* for a set of criteria *K*. Let f (.) be a particular criterion and *a* and *b* two actions, then the preference function is[16]:

$$P(a,b) = \begin{cases} 0 & iff(a) \leq f(b) \\ P[f(a), f(b)] & iff(a) > f(b) \end{cases} \quad (1)$$

For each couple of actions *a*, $b \in k$, the preference index is defined for action *a* with regard to action *b* over a set of criteria introduced by the decision-maker. Therefore the preference index is [14]:

$$\pi(a,b) = \frac{1}{k} \sum_{h=1}^{k} P_h\,(a,b) \quad (2)$$

For *h*= 1, 2, ……,*k*, where *k* being number of criteria selected by the decision maker (s).

In order to rank the actions by a partial preorder, both the outgoing flow (Φ^+) and incoming flow (Φ^-) are defined [14]:

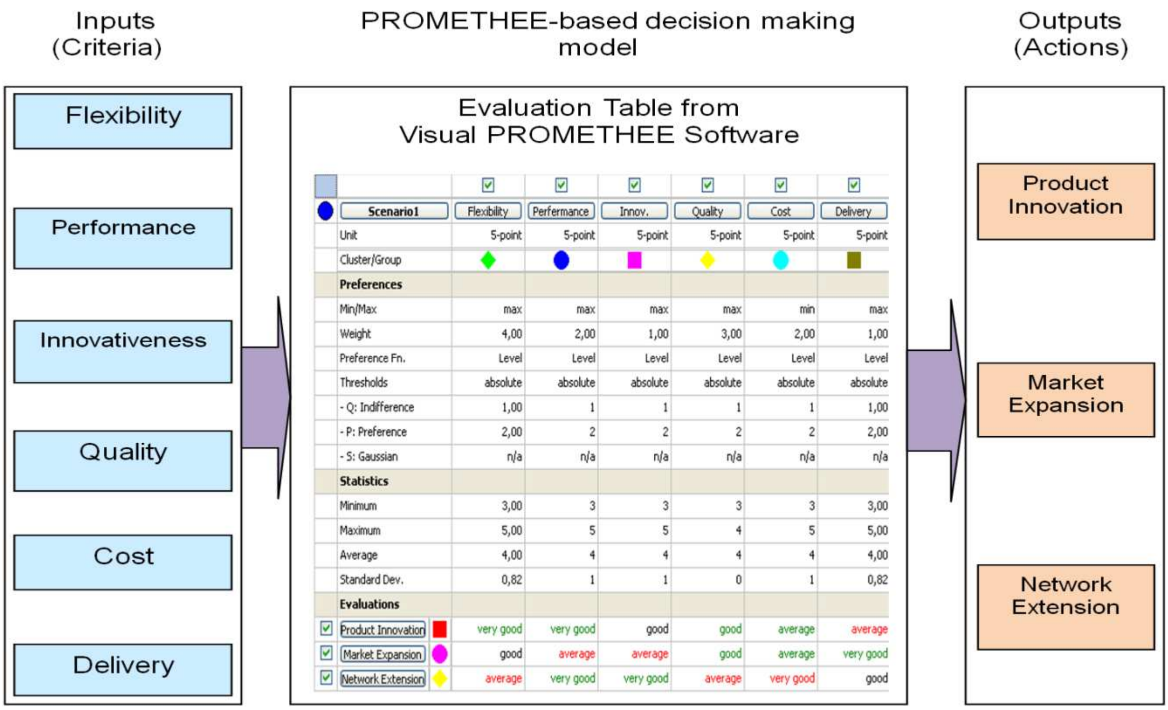
$$\emptyset^+(a) = \sum_{x \in k} \pi\,(a,x) \quad (3)$$

$$\emptyset^-(a) = \sum_{x \in k} \pi\,(x,a) \quad (4)$$

The larger Ph+, the more *a* dominates the other actions and the smaller Ph- the less *a* is dominated. For complete ranking, the net flow is introduced [14]:

$$\emptyset(a) = \emptyset^+(a) - \emptyset^-(a) \quad (5)$$

3.2. Solution Methodology: Work Environment



Scenario1		Flexibility	Performance	Innov.	Quality	Cost	Delivery
Unit		5-point	5-point	5-point	5-point	5-point	5-point
Cluster/Group							
Preferences							
Min/Max		max	max	max	max	min	max
Weight		4,00	2,00	1,00	3,00	2,00	1,00
Preference Fn.		Level	Level	Level	Level	Level	Level
Thresholds		absolute	absolute	absolute	absolute	absolute	absolute
- Q: Indifference		1,00	1	1	1	1	1,00
- P: Preference		2,00	2	2	2	2	2,00
- S: Gaussian		n/a	n/a	n/a	n/a	n/a	n/a
Statistics							
Minimum		3,00	3	3	3	3	3,00
Maximum		5,00	5	5	4	5	5,00
Average		4,00	4	4	4	4	4,00
Standard Dev.		0,82	1	1	0	1	0,82
Evaluations							
Product Innovation		very good	very good	good	good	average	average
Market Expansion		good	average	average	good	average	very good
Network Extension		average	very good	very good	average	very good	good

Fig. 2. *PROMETHEE-based decision making model.*

The proposed model methodology is shown in Fig. 2. The decision making model is based on PROMETHEE. Visual PROMETHEE software- academic version [16] is used in the model. The steps of PROMETHEE method implementation via Visual PROMETHEE software can be summarized as:

- The weights of each input can be entered directly by the decision maker or multi- criteria methods (such as analytic hierarchy process (AHP) [17] can be utilized. In current research, the direct method has been applied.
- The inputs of flexibility, performance, innovativeness, quality, cost and delivery are entered as criteria.
- The outputs of product innovation, market expansion and network extension are entered as actions (alternatives).
- Selection of criterion maximization or minimization (Min/Max) respectively.
- Assigning the preference functions and their thresholds.

4. Results and Discussion

The presented decision making model in this paper is used to select the proper manufacturing strategy and performance improvement in manufacturing SMEs.

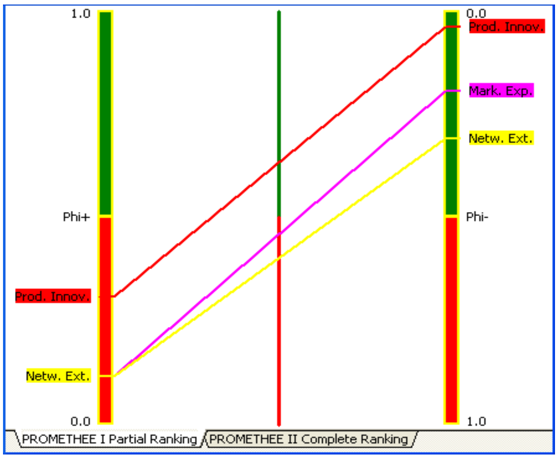


Fig. 3. *Partial ranking of alternatives.*

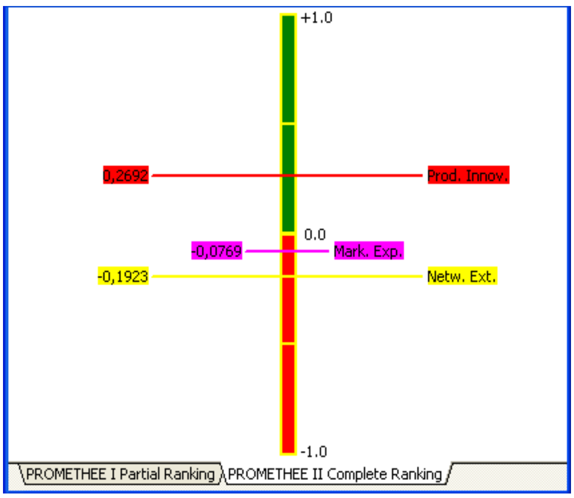


Fig. 4. *Complete ranking of alternatives.*

Fig.3 shows the partial ranking of the alternatives (product innovation, market expansion and network extension). For the decision example presented in this research, the figure shows that the product innovation is preferred to all other alternatives. This is followed by market expansion and lastly network extension.

The results above can be confirmed by PROMETHEE II complete ranking as shown in Fig. 4. The product innovation has a higher score of phi (0.2692) followed by market expansion with phi score of -0.0769 and network extension of -0.1923.

Fig. 5 shows the PROMETHEE diamond which is considered as a supporter to the results of both partial ranking (Fig. 3) and complete ranking (Fig. 4). The plane shown in this figure gives the phi net flow on the intermediate vertical line starting with +1.0 at the top to -1.0 at the bottom of the line. As the action, product innovation is on the top of the others, so this one is preferred to all other actions matching the results stated previously.

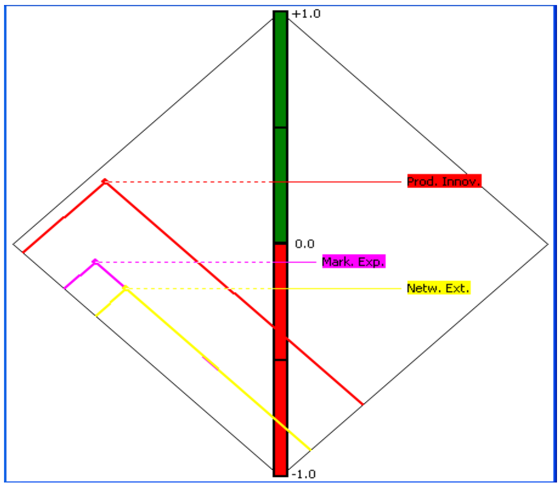


Fig. 5. *PROMETHEE diamond.*

The PROMETHEE flow table is shown in Table 1. The final results for the alternatives' ranking and their phi scores are displayed in the table. For instance, the product innovation is ranked as a first alternative with score of 0.2692 for net Phi and 0.3077 and 0.0385 for positive phi (Phi+) and negative phi (Phi-) respectively.

Table 1. *Flow table.*

Rank	Action		Phi	Phi+	Phi-
1	Product Innovation	■	0.2962	0.3077	0.0385
2	Market Expansion	●	-0.0769	0.1154	0.1923
3	Network Extension	◆	-0.1923	0.1154	0.3077

The above results show the utilizing of an outranking method (PROMETHEE) to select the most proper manufacturing strategy over a set of criteria. The rest of the results will demonstrate the effect of each criterion on the ranking process of the alternatives and the contribution of each manufacturing output to assign the most suitable action.

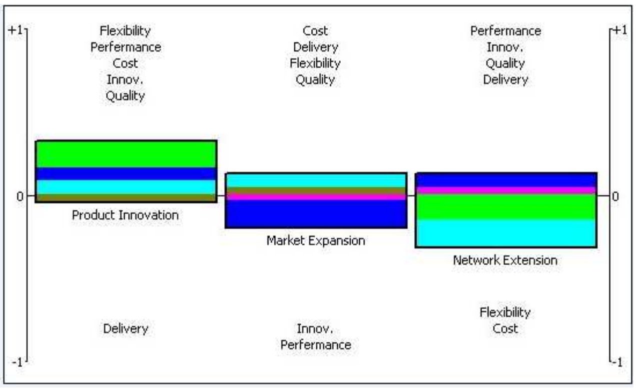


Fig. 6. PROMETHEE rainbow.

Fig.6 shows the PROMETHEE rainbow. The actions of product innovation, market expansion and network extension are drawn on a horizontal line. The vertical line represents the phi flow score starting from +1 at the top to -1 at the bottom of the line. It can be seen from the figure that each action is divided to a number of slices as the number of criteria. The width of each slice depends on the weight of the corresponding criterion. As displayed in the figure some of the slices are above the zero line (positive phi) and others are below it (negative phi). For instance the production innovation has a little negative contribution to its phi score. This action is very good on criteria: flexibility, performance, cost, innovativeness and quality, while it is bad on delivery criterion.

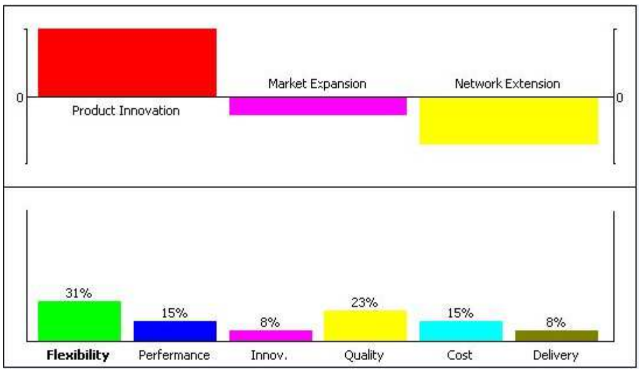


Fig. 7. Walking weights.

The walking weights of the criteria for the selected actions are shown in Fig. 7. The upper part of the figure shows the complete ranking of the actions with their corresponding phi score as explained in Table 1. The lower part shows the percentage weight for each criterion. For the current problem of alternatives' ranking, the corresponding weights of the six criteria are shown on the figure such as 31% is given to the flexibility while delivery has only 8% of contribution to complete ranking of the alternatives.

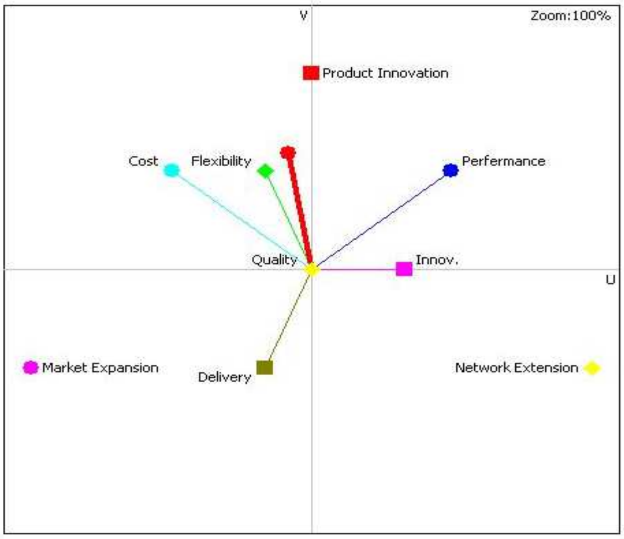


Fig. 8. GAIA plane.

Fig.8 shows the geometrical analysis for interactive aid (GAIA) plane. The plane displayed six dimensions as the number of the criteria taken for this decision problem. On the other hand, the actions on the plane are presented as points. The red line shown in the figure represents the preference index of an action to other action for the selected criteria.

Criteria with similar preferences, such as flexibility and cost, have axes that are close to each other while conflicting criteria (as delivery) have axes in opposite direction [18]. Based on these results, the product innovation is the best action associated to the criteria that have similar preferences. Also, it can be recognized from the figure that the actions market expansion and network extension are quite different from the other action.

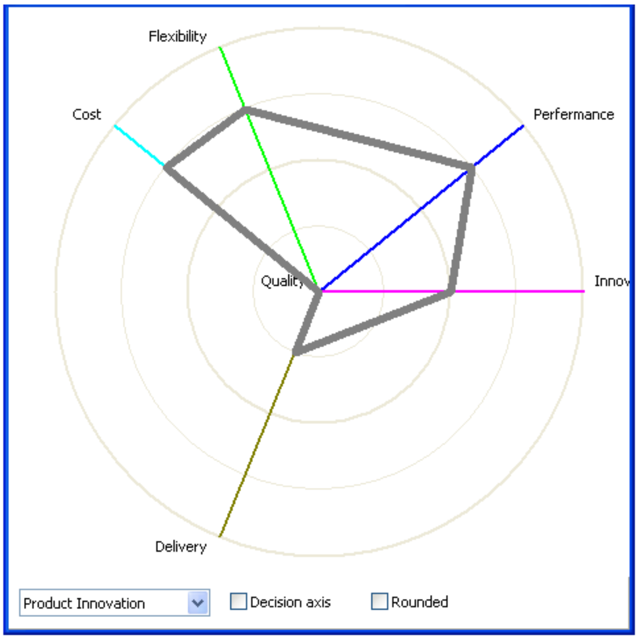


Fig. 9. GAIA web- Product innovation.

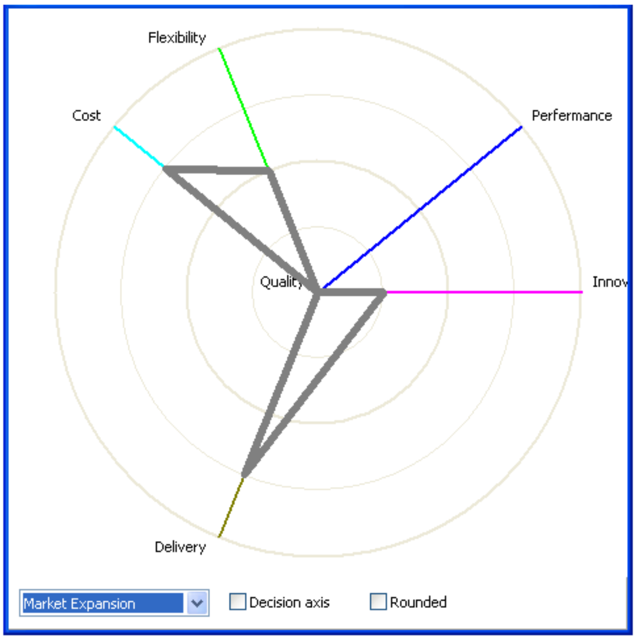


Fig. 10. *GAIA web- Market expansion.*

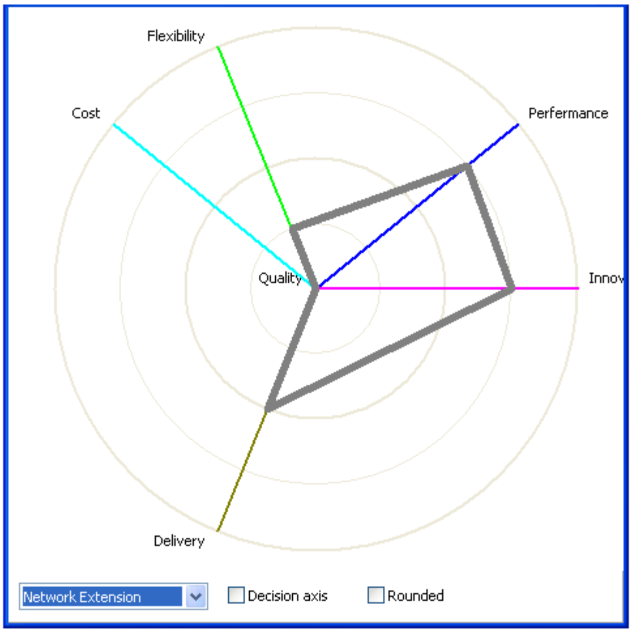


Fig. 11. *GAIA web- Network extension.*

Fig. 9-11 show the GAIA web for the three actions. The spider web shown in the figures displays the criteria polygon spaced around the centre of the web. As in GAIA plane (Fig.8), the criteria expressing similar preferences are located close to each other. For each criterion on the spider web the radial distance represents the net flow score where its value is equal to +1 on the outer circle and -1 at the centre [18]. It can be seen from the spider web of product innovation (Fig. 9) that the criteria flexibility and cost are very good for this action while delivery is a concern. For network extension (Fig.11) the criteria performance and innovativeness are very good. The two spider webs show opposite profiles for the actions.

5. Conclusions

In this research, a PROMETHEE-based decision model is proposed to define the most proper manufacturing strategy and performance improvement for manufacturing SMEs.

The outranking method used in the developed model has successfully implemented to handle the decision problem under study. The model was found to be applicable in finding the most preferable solution to select and rank a finite set of alternative actions among a set of manufacturing performance objectives.

To achieve this objective, a framework of a hierarchy structure was proposed. The structure consists of three levels. At the top the goal has been stated. The second and the third levels represent the criteria and their measures to select the alternatives.

The proposed methodology through the visual PROMETHEE software showed valuable aids to analyze the results and perform sensitivity analyses by decision-maker to identify the strengths and weaknesses for criteria and their contribution to select and rank the most preferable alternatives.

In summary, the results showed two parts of solutions: the first part demonstrated the actions' ranking of the proposed manufacturing performance improvement of a firm and the second part showed the priorities of the manufacturing outputs and their contributions to assign the most suitable action.

As a future work, the research can be expanded by participating of a group of decision makers to run different scenarios.

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