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Supplier Selection for Mixed-Model Production: A Case Study from the Apparel Industry

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Abstract
The mass-customization trend as flexible production philosophy has been adopted by many industries as a reaction to the fast changing customer demand environment. In relation to that mixed-model production (MMP) is a possibility for increasing flexibility, especially in the assembly department. However, many apparel companies have failed in their transition from traditional manufacturing to new, flexible manufacturing, which makes it difficult for them to be selected as suppliers who are capable of MMP. In most of the studies that have been done before, the problem of supplier selection was based on productivity and cost as the main selection criteria. As an alternative solution this research presents a new group of criteria for supplier selection with respect to the goal of MMP. The methodology of combining the analytical hierarchy process (AHP) with the support of the commercial software package Expert Choice and cluster analysis (CA) is proposed in this study. The results obtained present a new group of criteria, ranked by their importance, that the supplier needs to fulfil in order to be selected for MMP. Furthermore the large number of available suppliers was grouped into four clusters based on their similar characteristics by using CA. Finally the most acceptable cluster for MMP was selected using AHP. The methodology presented in this study can support the apparel industry in better decision making in the process of selecting the best group of suppliers for mixed-model production.

Key words: *apparel, mixed-model production, analytical hierarchy process, cluster analysis, supplier selection.*

Introduction

The newest trends in the apparel industry are characterised by the production of orders in small quantities, short lead times, a wide variety of styles and high quality. These trends require reactive production capacities to transform mass-production into mass-customisation. There is obviously a need for designing flexible manufacturing systems that will enable the production of many different styles of products with satisfactory quality in a short time. These flexible manufacturing systems are already successfully operating in the automotive industry [1]. Many car manufacturers use production lines that assemble different models of cars at the same time, without changing the design of the product line. These lines are known as multi-model and mixed-model assembly lines [2 - 5]. The production lines used in garment production are very similar to those in the automotive industry. However, the garment industry is still facing problems implementing flexible manufacturing systems. The most problematic area is the production line in the labour intensive sewing department, which is difficult to estimate accurately. This is also known as an NP-hard problem. Unlike an automobile production line, in apparel production there are additional factors that make efficient balancing of the line more problematic. The lower level of automation, the wide variety of materials with different properties, the need for a number of settings on the machines, and different levels of efficiency and capabilities of operators make an apparel production line inflexible when producing various product styles. One aim of this research is therefore to contribute insights and theory that may increase the flexibility of production plants engaged in the manufacturing of many different product styles.

Following the introduction, the research paper is organised into four sections: section 2 gives a brief introduction to the relevant literature; section 3 presents the methodology for supplier selection using a combination of the analytical hierarchy process (AHP) and cluster analysis (CA); section 4 summarises the results obtained from the case study conducted, and section 5 offers research conclusions.

Literature review

Studies related to the selection of suppliers date back to the 1960s [6], when this problem was called "vendor selection". When it comes to the selection of suppliers, several perspectives can be considered: selection criteria, methods used, goals and the industries to which supplies are sent. The criteria for any selection of suppliers have been the focus of analysis in a lot of research. Dickson [7] presents 23 criteria for the selection of suppliers, offering different combinations subject to achieving various goals in the process

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of supplier selection [8]. Referring to decision making (DM) techniques in the supplier selection process, Chai et al [9] performed an analysis of relevant literature between 2008 and 2012, finding that the AHP method is often either applied in combination with other methods or individually. Scientific studies between 2000 and 2008 [10] show that AHP combined with dynamic programming (DP) is an effective method for selecting a supplier and can take into account qualitative and quantitative multi-criteria in the decision making process. Vaidya and Kumar [11] analysed earlier research from 1983 to 2003 based on the AHP method, determining that AHP can be used generatively in decision making processes in 21% of instances and in manufacturing in 18% of cases. AHP can be applied across different industries. For example, Akarte et al., [12] developed web-based casting supplier evaluation for the automobile industry using AHP; Chan et al, [13] used AHP as a decision support for supplier selection, while Levary [14] used it for ranking foreign suppliers – both in the airline industry. Chan and Chan [15] developed a supplier selection model for advanced technology industry using AHP and quality management principles. Finally Ozkan et al, [16] used AHP for selection of an optimum computer and printer supplier.

A range of scientific studies have analysed the use of AHP in the process of optimum supplier selection, but studies related to supplier selection in the textile and apparel industry are relatively few [17]. Erbasi [18] used the AHP method to determine performance indicators for supplier selection in the Turkish textile industry; Gungor et al, [17] designed a 3-phase re-evaluation process for supplier selection using AHP, while Ertugul and Ozbay [19] used AHP combined with linear programming to provide the best supplier selection and distribution cost optimisation in a yarn production company. AHP for supplier selection in the garment industry was also used by Koprulu and Albayrakoglu [20], incorporating Web-HIPRE software tailored for the AHP model. Yayla at al., [21] also used multi-criteria evaluation methods – fuzzy TOPSIS – to select the best supplier in garment production. AHP was used by Shtub and Dar-el [22] to select the optimum apparel assembly system, and Sen and Cinar [23] used it for operator evaluation based on skills in the pre-allocation phase, with a combination of the min-max approach for grouping operators according to performance levels. The product grouping method or cluster analysis (CA) was also used by Anzanello and Fogliatto [24], where they selected the best variables for product clustering. Bottani and Rizzi [25] designed a multi-criteria approach for supplier and product selection that is orientated towards lead time reduction: they suggest CA for grouping if the number of alternatives needing to be selected is larger – closely related to the problem focussed on in this research. Chan and Chan [6] use AHP for supplier selection in the fashion industry, taking into account key factors for the quick response of suppliers in a fast changing fashion environment.

This research offers solutions to problems intrinsic to supplier selection for garment manufacture in mixed-model production. The problem with the selection of suppliers in various industrial sectors is already well known to researchers. The selection of suppliers is made on the basis of various criteria and for different purposes, selecting the most suitable supplier from few available suppliers. Two elements make this research unique:

- The aim of supplier selection, meaning the selection of a supplier capable of mixed-model production;
- The selection from a wider group of potential suppliers through grouping based on shared features.

This research focuses attention on decision making patterns, team building processes and selection methodologies that may generate candidates able to guarantee a consistently high level of objectivity.

Methodology

This research applies methodology for the Selection of Suppliers for Mixed-model Production (SSMMP) and the procedure for the selection of suppliers is heuristically presented (see model, ***Figure 1***). This methodology will incorporate the application of AHP and CA: AHP is deployed with the use of *Expert Choice* commercial software. The method ranks criteria in order of importance for supplier selection and for choosing the most suitable supplier for mixed-model production, while the application of CA allows the grouping of suppliers based on equivalent or similar features.

The methodology for selecting a supplier for mixed-model production consists of four stages:

1. Defining criteria important for the selection of a supplier for multi-model production;
2. Ranking the criteria according to importance;
3. Evaluation of existing suppliers based on previously defined criteria, and
4. The selection of the most appropriate group of suppliers for mixed-model production.

1: There is a two-stage definition of those criteria relevant for the selection of suppliers for mixed-model production. First, based on the literature review, the dominant group of criteria that play a significant role in the process of the selection of a supplier is determined. Then a team of professionals – key to the decision making process – is put together drawing on specialists from different segments of the garment industry. This selection of team members with different backgrounds and breadth of experience may generate greater objectivity in decision making. The decision making team used in this study is made up of six professionals from the ranks of top management in globally active and well-known purchasing houses, managers of suppliers for global fashion brands as well as researchers and consultants in the field of

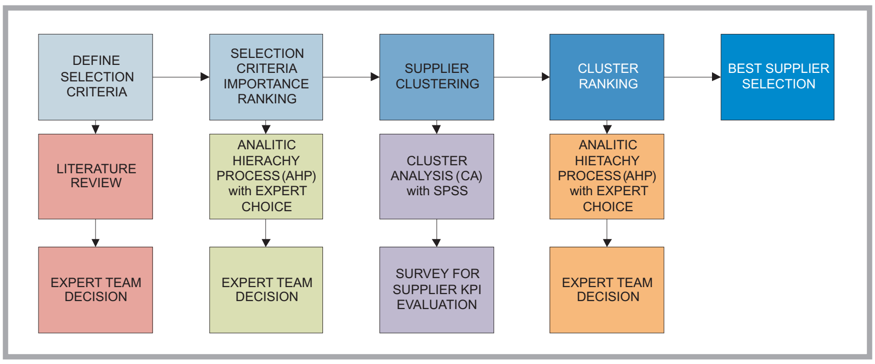

Figure 1. *Research model for supplier selection for mixed-model production.*

Table 1. Supplier selection criteria ranking.

Selection criteria	Team member						Criteria ranking result
	1	2	3	4	5	6	
Product quality level (QL)	0.349	0.246	0.277	0.084	0.227	0.308	0.248 (1)
Production flexibility (PF)	0/213	0.090	0.277	0.121	0.153	0.087	0.156 (2)
Product range (PR)	0.126	0.090	0.097	0.178	0.023	0.049	0.093 (6)
Technical capability (TC)	0.090	0.090	0.066	0.266	0.024	0.269	0.137 (3)
Production capacity (PC)	0.076	0.246	0.046	0.266	0.064	0.091	0.131 (5)
Management system (MS)	0.069	0.153	0.190	0.031	0.328	0.055	0.137 (4)
Logistics position (LP)	0.044	0.055	0.023	0.022	0.100	0.025	0.044 (8)
Financial position (FP)	0.034	0.028	0.023	0.031	0.064	0.117	0.049 (7)

garment production. First the team must select the key criteria – from a previously constructed group – related to the research problem i.e. how to select suppliers for mixed-model production.

2: Based on personal judgement, team members rank the key criteria for the selection of suppliers for mixed-model production. This ranking is constructed using a scale of values from 1 to 9, signifying the levels of importance in terms of achieving the goal stated [26, 27]. Then a comparison is performed between paired factors, arranged by *Expert Choice* – the software then deployed for data analysis [28, 29]. The end result is a ranking of key factors calculated as the geometric mean of individual values obtained from each team member.

3: In this phase, the existing suppliers are surveyed. The aim is to determine the extent to which certain factors are presented by a particular supplier. The survey was designed using key performance indicators (KPI) for work at a garment company [30]. KPI values of the company are used to determine the extent to which a particular factor is present in a particular supplier. The survey results are then translated into values of 1, 2 and 3: high, middle and low levels of satisfaction of specific factors. After this ranking, suppliers are arranged into groups based on similar features: each group contains elements that, while similar, are yet distinct from those in other groups.

4: Finally, taking into account previous factors ranked by importance, each group or cluster is valued according to whether the group fulfils the conditions of an ideal supplier for mixed-model production. The group of suppliers that fulfils the highest number of key factors can be judged most suitable to supply mixed-model production. Evaluation of the clusters is performed by each team member individually, and the end result for the most suitable supplier is the geometrical mean of the results of all members.

Defining the supplier selection criteria

Based on the literature review and consensus achieved among team members, a selection of the most important criteria for selecting a supplier capable of mixed-model production is made. These are as follows:

- **Financial position (FP)** refers to the willingness and ability of the supplier to produce the order for the price agreed with the customer.
- **Logistic position (LP)** refers to the supplier's ability to optimise the timing, transportation and storage costs of the goods.
- **Management system (MS)** is a system for interrelated departments to ensure not only satisfaction of legal conditions related to environmental, health and safety issues but also the provision of production planning, training, research and development.

Technical capability (TC) is the ability of the supplier, by using their capacity, to fulfil production requirements according to the accepted standards and customer needs.

- **Production capacity (PC)** includes all the supplier's necessary equipment, facilities, infrastructure, human resources and knowledge for the production of customer orders.
- **Production flexibility (PF)** is the ability of the supplier to respond swiftly to changes related to alterations of the product type.
- **Product quality level (QL)** refers to the implementation of the quality management system (QMS) with all necessary quality check stations to ensure efficient quality tracking and quality assurance (QA).
- **Product range (PR)** is the number of different types of products produced by a supplier over the study period.

Results

The ranking process of key criteria for supplier selection for mixed-model production

The ranking criteria important in the selection of a supplier for mixed-model production are employed applying the AHP method using *Expert Choice*. Data obtained from the six team members are summarised and the mean value calculated (see ***Table 1***).

Table 1 demonstrates the opinions of team members, who seem to believe the most important criteria for selection of a supplier for mixed-model production is product quality level (QL), with a value of 0.248. Next are factors: production flexibility (PF), technical capability (TC) and management system (MS), with values of 0.156, 0.137 and 0.137 respectively. Factors that have the lowest influence on mixed-model production and the selection of suppliers are financial position (FP) and logistic position (LP), with values 0.049 and 0.044, respectively. The inconsistency test is performed to test the consistency of participants' responses. A consistency ratio (CR) of less than 0.1 represents a satisfactory level of consistency [27]. The overall consistency ratio in this case is 0.06.

Evaluation of suppliers – case study

For the purpose of this research a case study was conducted in a global garment production company. The company faced the problem, analysed in this research, of selecting the most suitable suppliers in the Middle and Far East. The problem is further complicated by the fact that the company cooperated with a large number of suppliers: for the autumn/winter season 2012/2013 that number was 77. Difficulties were exacerbated by the presence of many different styles of products, which must be distributed by suppliers in an optimal way: in this case there were no fewer than 319 different styles. To negotiate this problem the company was trying to find a way to set up a more flexible system of production. For this, it is necessary to select suppliers capable of producing many different styles simultaneously. All the suppliers were surveyed and the level of satisfaction generated from previously established criteria.

Suppliers with similar properties were grouped by using CA with the support of SPSS software for statistical data analysis (see ***Table 2*** for clusters obtained).

Table 2 presents four types of results obtained from the cluster analysis. The initial cluster centre and final cluster centre results show every cluster's value of compliance to each selection criterion. In other words, the tables show how far each of the supplier clusters fulfils the criteria for selection required. The number of cases in each cluster result shows that the 77 available suppliers after the evaluation process are grouped into 4 clusters. The number of cases per cluster ranges from 13 to 25. The iteration history result shows differences between the clusters by calculating the minimum distance between the cluster centres, which is 2.236.

Supplier ranking

The four clusters obtained with different characteristics are ranked according to which best fulfils the criteria of selection. For this, *Expert Choice* was used again (see ***Table 3*** for results from all members of the team).

Table 3, containing the results of all team members, shows that suppliers belonging to cluster 4 have the highest predisposition to be selected for multi-model production by a sourcing company. This suggests that cluster 4 has the most suitable suppliers in terms of fulfilling key selection criteria. The CR in this case is calculated as 0.05.

Figure 2 illustrates that clusters C3 and C4 perform better than others. By comparing these two clusters, it stands out that C3 performs considerably better that C4 in criteria PF, MS and LP, while having the same performance for criteria PR and FR. C4 performs better in criteria PC, TC and QL and the chriteria where C4 performed better than C3 are ranked as more important that those where C3 performs better. Based on these observations, cluster C4 was selected as the most appropriate cluster of suppliers for mixed-model production. However, this study only presents a model where the most important criteria for supplier selection are introduced, and based on that the most suitable suppliers for MMP are selected. This study will be extended to practical implementation of the MMP phenomenon in one of the selected companies. The future research will examine the factors the influence of implementation of MMP in the apparel industry and the benefitof its implementation in meeting actual production trends.

Table 2. *Supplier cluster analysis results.*

Initial cluster centers	Criteria	Cluster 1	Cluster 2	Cluster 3	Cluster 4
	QL	2.00	2.00	2.00	3.00
	TC	1.00	2.00	3.00	3.00
	PC	1.00	2.00	3.00	3.00
	PR	3.00	3.00	3.00	3.00
	PF	3.00	1.00	3.00	1.00
	MS	1.00	2.00	3.00	3.00
	FP	3.00	3.00	3.00	3.00
	LP	3.00	3.00	3.00	2.00

Final cluster centers	Criteria	Cluster 1	Cluster 2	Cluster 3	Cluster 4
	QL	1.38	1.36	2.00	2.30
	TC	1.00	2.44	2.85	2.91
	PC	1.00	2.00	2.62	2.87
	PR	2.13	3.00	3.00	3.00
	PF	1.44	1.28	3.00	1.13
	MS	1.00	2.00	2.62	2.87
	FP	3.00	3.00	3.00	3.00
	LP	3.00	3.00	3.00	2.52

Number of cases in each cluster			
	Cluster	1	16
		2	25
		3	13
		4	23
	Valid		77
	Missing		0

Iteration history	Change in cluster centers 1	2	3	4
1	1.053	0.727	0.386	0.673
2	1.092	0.446	0.221	0.276
3	0.000	0.000	0.000	0.000

Convergence achieved due to no or small change in cluster centers. The maximum absolute coordinate change for any center is 0.000. The current iteration is 3. The minimum distance between initial centers is 2.236.

Table 3. *Supplier cluster ranking.*

Cluster no.	Team member 1	2	3	4	5	6	Cluster ranking result
C3	0.367	0.328	0.370	0.331	0.337	0.315	0.341 (2)
C4	0.329	0.374	0.334	0.362	0.342	0.365	0.351 (1)
C2	0.204	0.186	0.177	0.206	0.183	0.193	0.191 (3)
C1	0.100	0.112	0.119	0.102	0.138	0.126	0.116 (4)

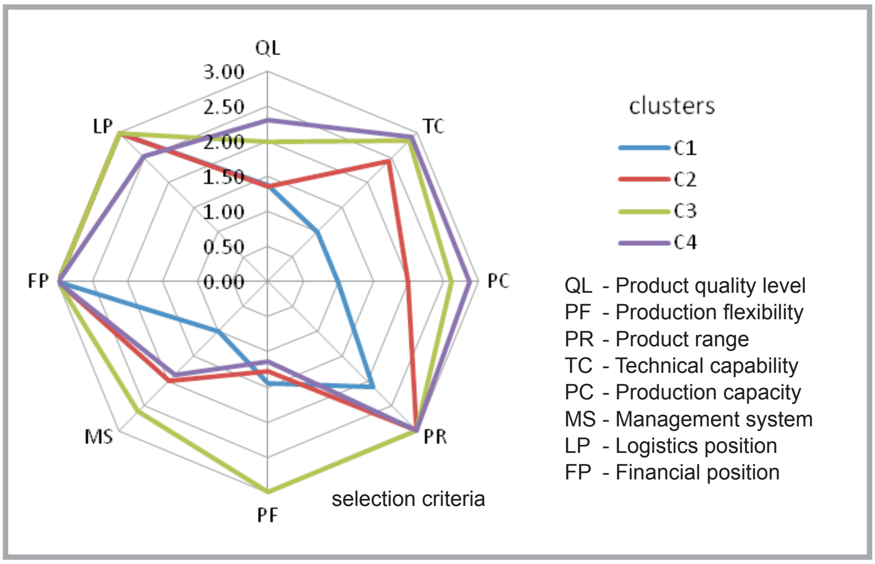

Figure 2. *Supplier cluster comparison.*

Conclusion

The research presents an heuristic model for supplier selection in the garment industry, suggesting which is most capable of mixed-model production. The model allows the selection of the most appropriate supplier from a larger group of potential ones through their grouping into clusters. The model incorporates the application of AHP and CA with AHP applied for ranking key criteria for the selection of suppliers and CA for grouping suppliers based on similarities. Finally AHP is used to rank the most appropriate group of suppliers for mixed-model production.

The ranking of criteria adopted is based on the opinions of six industry professionals and the evaluation of suppliers on survey data.

From survey data, it is possible to extrapolate 8 key factors for the selection of suppliers for mixed-model production: product quality level is selected as the most important and logistic position as the least significant. In addition, the evaluation of suppliers finds that one group which meets most of the higher ranked selective criteria are best suited to be selected for multi-model production.

One of the limitations in this research is that selection criteria are defined on the basis of both the literature review and the opinion of a group of six industry professionals. Nevertheless the work done here creates an opportunity for further research which might include more members for conducting surveys that will define the selection criteria, opening the way for a deeper understanding of those criteria not touched on in this research. A final limitation that should be mentioned is that the evaluation of suppliers is based on a case study conducted in a global garment company: future research might gain greater insight if it used a larger data base – a wider, more heterogeneous group of companies – perhaps with different sizes and areas of operation. This might allow the generation of further heuristic modelling and deeper insights into supplier selection and the nature of mixed-model production.

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