Suppliers Selection In Manufacturing Industries And Associated Multi-Objective Desicion Making Methods: Past, Present And The Future

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Abstract

Nowadays, many manufacturing companies have decided to use other companies' competencies and outsource part of their manufacturing processes and business to suppliers globally in order to reduce costs, improve quality of products, explore or expand new markets, and offer better services to customers, etc. The decisions have rendered manufacturing organizations with new challenges. Organizations need to evaluate their suppliers' performance, and take account of their weakness and strength in order to win and survive in highly competitive global marketplaces. Hence, suppliers evaluation and selection are taken as an important strategy for manufactring enterprises. This paper aims to provide a comprehensive and critical review on suppliers selection and the formulation of different criteria for suppliers selection, the associated multi-objctive decision makings, selecion algorithms, and their implementation and application perspectives. Furthermore, individual and integrated suppliers selection approaches are presented, including Analytic hierarchy process (AHP), Analytic network process (ANP), and Mathematical programming (MP). Linear programming (LP), Integer programming (IP), Data envelopment analysis (DEA) and Goal programming (GP) are discussed with in-depth. The paper concludes with further discussion on the potential and application of suppliers selection approach for the broad manufacturing industry.

Keywords: Suppliers selection, Multi-objective decision makings, Selection algorithms, E-manufacturing

Introduction

Nowadays, outsourcing part of manufacturing and business processes in order to win and survive in the highly competitive global marketplace is

becoming increasingly important for manufacturing companies. They are practicaly used with delicate strategies in different sections of manufacturing organisations, such as IT, raw materials, sales, logistics, and transportation as needed with various managements strategies. According to the result of a survey by Accenture Consulting (2005), 80% of correspondent companies are received services and parts from third party logistic providers and spent almost half of their budgets on outsourcing. Moreover, one of the main concepts for product realisation process from design stage to delivery of final product including both goods and services is selecting the best supplier and optimising purchasing strategy. Hence, it is necessary to evaluate suppliers performance before using their competencies.

In this paper, a comprehensive and critical review on suppliers selection and the associated enabling technologies is presented, further supported with implementation and application cases and analysis. The review summarizes the past, highlights the state-of-the art and further sheds the light of the future in the subject domain.

Conception of suppliers selection

Supplier selection is one of the main concepts of this research and is considered as strategic procurement management in the supply chain. Purchasing raw materials needs accurate decision making strategies to find the best suppliers to assure long term feasibility of an organisation (Thompson, 1990). Existing literature and supplier selection problems identified by researchers will be discussed in this section based on various supplier selection criteria.

Dobler *et al.*, (1990),Willis *et al.*, (1993), and Khir and Cheng, (2012) stated that the procurement department plays a significant role in enterprise as their managers are responsible for making critical decisions to select appropriate suppliers in order to reduce ordering/purchasing expenses. To eliminate the complexity of supplier selection as a multi-objective model, a broad approach to choose the best supplier was proposed and launched by Weber and Current (1993). Their main aim was to reduce all expenses caused by purchasing the enterprise requirements from various suppliers each time. This model proposed a way to estimate changeable conditions of selected suppliers over time. Hence, management was able to undertake essential actions.

A strategic evaluation in manufacturing sectors not only provides more business opportunities and adequacy to consumers, but also estimates, monitors, and evaluates the customer demand (Hassanzaedeh and Cheng, 2013). Although, there were only few articles emphasizing decision making until Weber and Current (1993), Rosenblatt *et al.*, (1998) had a comprehensive articles review and stated another supplier selection

limitation, which was the amount and purchase time of products or services. By using *'kanban'* or 'just in time' (JIT) systems and specifying an exact quantity of requirements from an allocated supplier, the limitation seems to have been overcome.

Providing a long term deal and a reasonable value to buyer, as well as removing possible risk for customer and retailer, are the final goal of supplier selection as detailed by Keskin *et al.,* (2010). The authors believed that human decisions to assess and choose best suppliers are the reasons for making the supplier selection area complicated and uncertain. They mentioned that the financial reasons were the main concern in traditional suppler selection issues.

As it mentioned, many authors have explored different problems and tried to solve them by using different techniques. However, the emphasis on time, cost and quality is common to all.

Formulation of the criteria for suppliers selection

Finding the appropriate supplier is a difficult duty in procurement departments as suppliers have different strength and weakness. Although it might be easier to consider only a single criterion in final decision, multi-criteria decision making will be necessary in some cases. Many researchers analysed selection criteria and measured supplier performance since 1960. There have been four comprehensive reviews, namely Dickson (1966), Weber *et al.*, (1991), Davidrajuh (2000), and Ho *et al.*, (2010), on supplier selection criteria.

Past to 1966

Dickson (1966) designed a questionnaire to identify important criteria in supplier selection. He sent his survey to 273 procurement staff and managers, who were members of the National Association of Purchasing Managers, including agents and managers from the United States of America and Canada. As a result, he identified 23 criteria and the significance of each criterion based on five different scales, extreme, considerable, average, slight and, no importance. As shown in (Table 1), the ability to meet quality standards, the ability to deliver the product on time, and performance history were the most significant performance measures among all 23 criteria in supplier selection.

Table 1: Comparison of suppliers selection criteria rank

Rank	Dickson, (1966)	Weber, (1991)
1	Quality	Net Price
2	Delivery	Delivery
3	Performance History	Quality
4	Warranties	Production Facilities
5	Production Facilities	Geographical Location
6	Net Price	Technical Capability
7	Technical Capability	Management and Organization
8	Financial Position	Reputation
9	Bidding Procedural Compliance	Financial Position
10	Communication System	Performance History
11	Reputation	Repair Service
12	Desire for Business	Attitude
13	Management and Organization	Packaging Ability
14	Operational Controls	Operational Controls
15	Repair Service	Training Aids
16	Attitude	Bidding Procedural Compliance
17	Impression	Labour Relations Records
18	Packaging Ability	Communication System
19	Labour Relations Records	Reciprocal Arrangements
20	Geographical Location	Impression
21	Amount of Past Business	Desire for Business
22	Training Aids	Amount of Past Business
23	Reciprocal Arrangements	Warranties

Period of 1966-1991

Two decades after the Dickson research, Weber *et al.,* (1991) reprioritized 23 the Dickson criteria by reviewing 74 articles published in the manufacturing and retail sectors between 1966 and 1991. This comprehensive study showed that during almost 20 years, the priority and ranks of criteria has changed (see also Table 1). Net price, the ability to meet quality standards, and the ability to deliver the product on time are considered as the most important factors, following by production facilities, geographical location, and technical capability. Comparing criteria ranking in both the Weber and Dickson research shows factors such as quality, delivery, and net price are always considered as important factors. However, the surprise could be the rank changes of geographical location (from 20^{th} stage to 5^{th} stage) which, it is argued, is the result of economic globalisation (Mendoza et al., 2008).

The top ten criteria ranked in the Weber research based on the number of articles published to address specific criterion presented ‘quality’

as the clear top being cited in 80% of all research papers (Table 2). Moreover, 'delivery' and 'quality' were cited in 58%, and 52% of research articles respectively. Zhang *et al.,* (2003) undertook a similar study as Weber by reviewing 49 articles based on the 23 Dickson criteria and presented almost the same result as Weber.

Table 2: Top 10 suppliers selection criteria (Weber, 1991)

Criteria	**Articles**	**%**
Net Price	61	80
Delivery	44	58
Quality	40	52
Production Facilities	23	30
Geographical Location	16	21
Technical Capability	15	20
Management and Organization	10	13
Reputation	8	11
Financial Position	7	9
Performance History	7	9

Period of 1991-2001

Industrial organisations with good purchasing strategies are capable of having long-term viability and survival in highly competitive markets (Kinney, 2000). He divided his articles into two parts. He proposed outsourcing, global sourcing, supply chain optimisation, and supplier consolidation as four critical strategies for continuous improvement in industrial companies. Cheraghi *et al.,* (2001) published a paper in which the 23 Dickson criteria have been reviewed in almost 100 research articles between 1991 and 2001. He claimed that 'quality', 'delivery', and 'net price', with 79%, 77%, and 67% articles citation counts, to be the most important criteria. Criteria such as `desire for business`, `amount of past business`, and `warranties` were not cited at all (see Table 3). Furthermore, the authors compared their findings with the Weber *et al.,* (1991) study which showed the significant variation in the relative importance of different critical success criteria. Table 3 below shows the important change of criteria ratings during 1966-1991 versus 1991-2001.

Table 3: Comparison of suppliers selection criteria rank

Rank	Weber (1991)	Articles	%	Cheraghi *et al.*, (2001)	Articles	%
1	Net Price	61	80	Quality	31	79
2	Delivery	44	58	Delivery	30	77
3	Quality	40	52	Net Price	26	67
4	Production Facilities	23	30	Repair Service	11	28
5	Geographical Location	16	21	Technical Capability	11	28
6	Technical Capability	15	20	Production Facilities	10	26
7	Management and Organization	10	13	Management and Organization	7	18
8	Reputation	8	11	Financial Position	7	18
9	Financial Position	7	9	Attitude	5	13
10	Performance History	7	9	Performance History	4	10
11	Attitude	6	8	Communication System	4	10
12	Repair Service	6	8	Reputation	4	10
13	Operational Controls	5	7	Procedural Compliance	2	5
14	Packaging Ability	5	7	Geographical Location	2	5
15	Impression	4	5	Impression	2	5
16	Communication System	3	4	Reciprocal Arrangements	2	5
17	Reciprocal Arrangements	3	4	Labour Relations Records	1	3
18	Labour Relations Records	3	4	Training Aids	0	0
19	Training Aids	3	4	Operational Controls	0	0
20	Procedural Compliance	2	3	Packaging Ability	0	0
21	Desire for Business	2	3	Desire for Business	0	0
22	Amount of Past Business	1	1	Amount of Past Business	0	0
23	Warranties	1	1	Warranties	0	0

The authors' findings shows that in spite of traditional factors such 'quality' and 'price', non-traditional performance aspects such as 'just-in-time communication', 'continuously process development', and 'supply chain improvement' could be a reason for change in importance of supplier selection criteria.

2001 to present

Weber *et al.*, (1991), Degraeve *et al.*, (2000), De Boer *et al.*, (2001), and Cheraghi *et al.*, (2001) were four papers reviewing the literature regarding supplier selection development. Since these articles review the literature up to 2000, Ho *et al.*, (2010) published a comprehensive literature review based on 78 research articles searched and collected via Emerald, Ingenta, Meta- Press, ProQuest, and ScienceDirect on the multi-criteria decision making approaches for supplier evaluation and selection models between 2000 and 2008. The main objective of their article was to identify the most popular criteria considered by the decision makers for assessing and choosing the best supplier.

Table 4: Suppliers selection criteria, Ho *et al.*, (2010)

Criteria	Articles	%
Quality	68	88
Delivery	64	82
Price/Cost	63	80
Manufacturing Capability	39	50
Service	35	45
Management	25	33
Technology	25	33
Research and Development	24	31
Finance	23	29
Flexibility	18	24
Reputation	15	20
Relationship	3	4
Risk	3	4
Safety and Environment	3	4

Among hundreds of criteria they supposed, Table(4) indicates that the 'quality', 'delivery', 'price/cost', and 'manufacturing capability' were the most popular criteria, as these criteria were sited in 88%, 82%, 80%, and 50% of the research papers, followed by 'service', 'management', 'technology', 'research and development', 'finance', 'flexibility', 'reputation', 'relationship', 'risk', and 'safety and environment'.

Suppliers selection methods

Due to uniqueness of each problem, it is hard to introduce a specific solution for every problem. Different type of methods or combination of methods for supplier evaluation and selection are available to help decision makers. In order to increase productivity and provide customer satisfaction, organisations need to have close relation with suppliers. In fact, to reduce cost and provide better services, organisations seek to outsource part of their product or services. Actually, they need to evaluate and monitor supplier performance over time. Hence, organisations pay considerable attention to supplier evaluation and selection methods. Agility and flexibility are basic requirements of a desirable model among different selection models. Finding the best supplier, who may have various weaknesses and strengths based on the enterprise short and long term goals, are considered as an uncertain task. In the simplest scenario, decision makers only consider a single criterion, for instance, either quality or price. However, it would be very optimistic to attempt to survive in highly competitive market if companies only consider one criterion instead of multiple criteria.

Karimi and Rezaeinia (2014) defined supplier selection as a multiple criteria decision-making (MCDM) problem. Sarkis and Talluri (2002) and

Chai *et al.*, (2013) stated that to enable the simplification of various criteria and obtain a best solution, MCDM is the most desired method for management. To deal with this problem, many authors proposed various individual supplier evaluation approach, such as, analytic hierarchy process (AHP), analytic network process (ANP), mathematical programming (MP), data envelopment analysis (DEA), and goal Programming (GP). Moreover, some researchers proposed to use an integrated (mixed) approach of the aforementioned methods.

Individual approaches

Based on the problems in different cases or industries, the researcher decided to use either individual approaches or integrated (mixed) approaches. Ho *et al.,* (2010) published a comprehensive literature review to show the popularity and capability of individual and integrated methods in different researches and industries. Among 46 journal articles, 23 papers (50%) formulated different types of mathematical programming individually as the most appropriate solution for various industries and organisations. These various MP models were applicable in different organisations, such as, bottling machines and packaging lines manufacturing, agricultural and construction equipment manufacturing, electronic components manufacturing, telecommunications industry, supplier evaluation and management accounting, communications industry, nuclear power industry, consumer products manufacturing, pharmaceutical industry, aviation electronics manufacturing, hydraulic gear pump manufacturing, and hydraulic gear pump manufacturing.

An AHP model was proposed individually in 15% (seven out of 46) of papers while ANP was proposed in almost seven percent of papers (three out of 46). Both AHP and ANP were applicable in manufacturing industries, such as, automobile castings, bicycles manufacturing, semiconductor assembly and equipment manufacturing industry, furniture industry, airline industry, printer manufacturing, electronic industry, and high technology metal-based manufacturing.

(1) Analytic Hierarchy Process (AHP)

AHP is a modern MCDM approach proposed by Saaty (1980) which has been extensively using linear weighting techniques to analyse both quantitative and qualitative performance when multiples criteria and sub-criteria should be used. This method not only recommends a correct decision, but also enables decision makers to form a decomposition of complex problems into hierarchies which comprise different levels such as goal allocated criteria, for example, customer satisfaction, product/service, financial, human resource, and organizational effectiveness, , and the

alternative solutions (Benyoucef, 2003). To categorise criteria in order to have a mathematically optimal solution, a matrix algebra and paired-wise comparison method is used.

Akarte *et al.,* (2001) proposed a web-based decision support system for casting supplier evaluation by using AHP method. The authors specified 18 criteria, for example, Quality, Cost, and Delivery, and categorised into four groups, namely, product development capability, manufacturing capability, quality capability, and cost and delivery. Customers need to sign up to their system first, and then choose the casting specification located in the portal. Chan (2003) designed a method called chain of interaction using AHP to create the overall weights for nominated suppliers based on the relative importance ratings. Recently, Kar (2014) proposed a fuzzy AHP approach for group decision making. To initialise and integrate the preferences of the group of decision makers, the author mixed fuzzy AHP with the geometric average method. However, having a long and slow process time is one of the main drawbacks of AHP method due to its reliance on a subjective, paired-wise, comparison method for assessing alternatives (Wang *et al.,* 2010). Moreover, to add a new criterion during a process, whole calculations must be repeated from the beginning.

(2) Analytic Network Process (ANP)

The analytic network process ANP is a generalization of the AHP, solving complex decision problems. The main differences between these two models is in their structure, within which the hierarchy includes a goal, levels of criteria and connection between criteria and alternatives, while the latter one includes clusters, elements, and links(Saaty, 1996). In fact, Saaty introduced an extended model of AHP to solve the problem of interrelation among different criteria or alternatives.

Similar to AHP and other methods, ANP proposes to select and optimise the best supplier. A simple cluster model with N suppliers and different decision attributes is shown is Figure 1. To clarify related alternatives, factors are provided in supplier performance criteria and provider capabilities. Hence, this model consists of N clusters, alternatives, performance criteria, and provider capability (Bayazit, 2006). In contrast with AHP, which offers hierarchical and linear structure, ANP offers a nonlinear structure. Figure 1 below shows the structure differences in AHP and ANP.

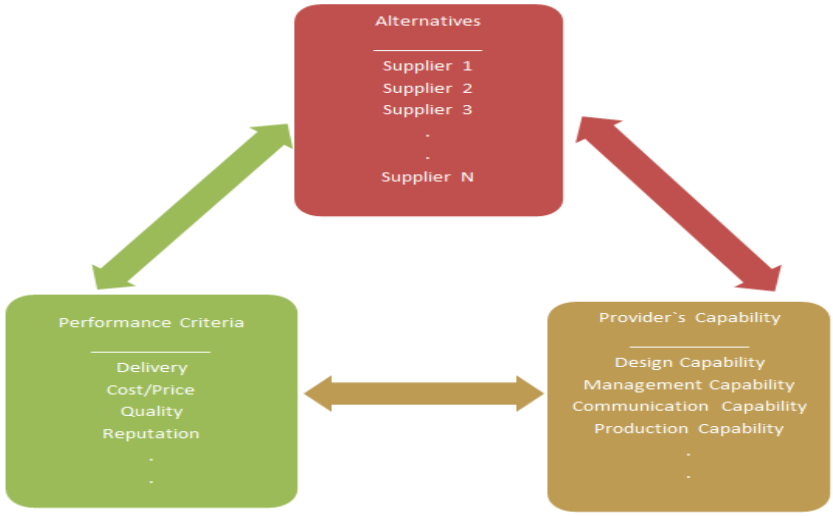

Figure 1: ANP Model Instance, (Bayazit, 2006)

The advantage of ANP in comparison with AHP is the former one is able to deal systematically with all kinds of dependence and feedback in a decision system (Bayazit, 2006). With respect to logistic factors and performance activities, Sarkis and Talluri (2002) proposed ANP to choose the best supplier in enterprises. They argued that not only internal interdependency needed to be considered in the evaluation process, but also that selection criteria would impact each other. However, being suitable for only long term strategic decisions is one of the drawbacks of ANP method. Moreover, timely and complex pair-wise comparisons require considerable effort to obtain a best result, which still might lead into wrong results.

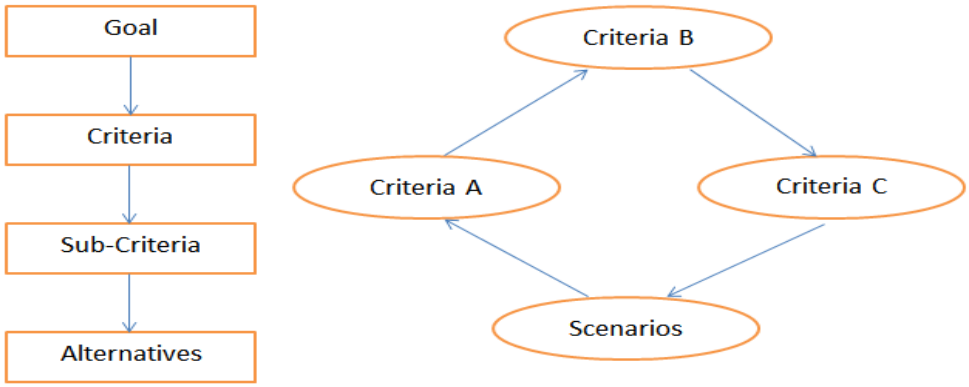

Figure 2: Hierarchal structure (left) against network structure (right)

(3) Mathematical Programming (MP)

Mathematical Programming (MP) or optimisation is an operation research (OR) technique allowing decision makers to generate the best

solution and optimise the models. Liberti (2009) defined MP a "descriptive language used to formalise optimization problems by means of parameters, decision variables, objective functions and constraints, while such diverse settings as combinatorial, integer, continuous, linear and nonlinear optimization problems can be defined precisely by their corresponding formulations".

Narasimhan *et al.*, (2006) presented a MP model to identify best suppliers and supplier bids when various products with various ranges of life cycles were being considered. Esfandiari and Seifbarghy (2013) presented a MP model by setting purchasing cost, rejected units, and late delivered units as constraints while maximising the quality was the main objective function. There are various types of Mathematical programming categorised as:

i. Linear Programming

LP is mathematical programming in which a linear function of a number of variables or criteria is selected in order to minimise or maximise. All variables are allocated to different kinds of constraints in the form of linear inequalities. Moore and Fearon (1973) and Pan (1989) used LP for selection evaluation based on criteria such as price, quality, and delivery. By minimising the total cost and setting quality of products and delivery time of final product as constraints, the authors optimised their model.

Talluri and Narasimhan (2003, 2005) presented a model in which customers have to set the target score. This model utilises two different LP models for maximising and minimising the supplier performance in order to provide a broad understanding of a supplier performance. Two years later, these researchers developed a Data Envelopment Analysis model (DEA) for telecommunications companies to compare the new results with their previous results. Esfandiari and Seifbarghy (2013) proposed a multi-objective LP model in which the total scores from the supplier selection procedure is maximised while purchasing cost, rejected units, and delayed delivered units were minimised.

ii. Integer Programming

Methods such as LP and integer linear programming (Talluri, 2002; Hong *et al.*, 2005), and goal programming (GP) have been applied to help decisions makers on supplier selection evaluation. Feng *et al.*, (2001) presented a stochastic integer programming (SIP) model for simultaneous selection of tolerances and suppliers based on the quality loss function and process capability index. The main philosophy used in the SIP model was inspired by concurrent engineering as it emphasized assimilability, quality, and cost, at the product design stage. The process capability index is considered as a relational link between manufacturing cost and the required

level of manufacturing yield. In their proposed model, a combination of manufacturing cost and quality lost has been minimised as the objective function. The authors believed that their SIP model had advantages such as 1) removing the regression errors, 2) considering asymmetric and symmetric tolerance, and 3) applying the process capability level in both component level and the assembly level.

Amid *et al.,* (2009) formulated a mixed integer model to consider simultaneously the imprecision of information, and determine the quantities to each supplier based on price breaks. The proposed model set different objective functions by minimizing the net cost, net rejected items, and the net late deliveries. Satisfying capacity and demand requirement are also set as two difference constraints.

iii. Data Envelopment Analysis

DEA is a non-parametric mathematical programming model developed by Charnes, Cooper and Rhodes (1978) for measuring the relative efficiency of decision-making units (DMUs), which categorise into two units, multiple outputs and multiple inputs (Truong, 2010). The former one includes criteria such as quality, benefits, customer satisfaction, while the latter one includes criteria such as cost, material resources, and human resources. In the whole supply chain management network, DMUs consist of different organisations from manufacturers and suppliers to wholesalers and retailers.

Forker and Mendez (2001) suggested that DEA could be applied not only in supplier evaluation, but also in the airline industry, banking, academic organisations, power plant, and health care. The authors introduced the 'best peer' supplier which refers to those suppliers who are not suitable for the organisation but, however, have the ability to improve their performance by minimum effort. Hence, the optimum ratio of a single input to multiple outputs needs to be calculated in order to filter the total results. Furthermore, Wu *et al.,* (2007) argued that one of the key advantages of DEA, which makes it a suitable method for evaluating and executing management decisions, is its capability to deliver a different range of critical decision models. Hence, managers have a variety of options in order to develop their operations.

However, the main practical problem in using DEA is the weights flexibility problem, (Kumar and Jain, 2010) due to offering a simple framework in order to convert decision maker judgments into the decision making process. The authors used the DEA approach for green environmental supplier evaluation by encouraging suppliers to go with green and monitoring carbon footprints in order to survive in highly competitive markets.

iv. Goal Programming

Dealing with multi-criteria decision issues, where the predefined goals cannot concurrently be optimized, GP was proposed for the first time by Charnes and Cooper (1961) in order to provide a set of acceptable solutions. Many researchers and industries tend to use this model because GP can offer the most suitable solution to decision makers as well as its ease of use and adaptability. Wadhwa and Ravindran (2006) proposed a pricing model under quantity discounts to represent the purchasing cost by using the GP model, as they believed that GP model is more suitable for vendor selection process, based on a set of constraints and criteria. This model was designed to cope with one buyer and one product, and developed for more than one buyer and product to show the differences of results. Khorramshahgol *et al.* (2014) proposed a GP model to cope with the swap problem of firms in oil industries. Three different GP-based scenarios were proposed where each scenario includes five objective functions and various constraints. The main aim of this research was to persuade managers to consider viable alternatives, preferences, 'trade- off's and outcomes before making any decision for buying products. Table 5 indicates the description, advantages, limitations, and application area of all the aforementioned methods. All methods have different advantages and limitations, and also have been used in different manufacturing sectors. MP models are able to offer a best solution to complex problems as well as optimising resource allocation within manufacturing sectors to establish desired goal. In addition, MP models are ideal for both single-objective models and multi-objective models because of ease of use, confidence in compromise solutions, and decision maker acceptance.

Integrated approaches

In different scenarios, only applying an individual approach could not effectively solve the problems. Many authors proposed integrated approaches in order to use two or more models. Hence, decision makers were able to combine various approaches and get benefit from the advantages of different models. It is also essentially important in their implementation and application particularly in the e-manufacturing and e-business context (Cheng and Bateman, 2008).

Ramanathan (2007) introduced an integrated DEA with AHP model in order to evaluate supplier performance by analysing information obtained from manufacturing cost. In this research, three different kinds of DEA, namely traditional, super-efficiency, and assurance region, combined with AHP to show which combined model can minimise the manufacturing cost. Sevkli *et al.,* (2007) developed a data envelopment analytic hierarchy process (DEAHP) methodology in the TV manufacturing industry. Their finding shows that DEAHP can provide a better decision as its application is

more suitable for high-value components where purchasing criteria are variables. To compare DEAHP with AHP, the authors defined the criteria for supplier selection by designing an AHP tree, and then assigned different weightings for predefined criteria to specify an overall score for each supplier. The main manufacturing and business criteria they used in the research were reputation, price, technical capability, production capacity, and lead-time.

Table 5: Comparison of different decision-making methods

	Description	Advantages	Limitations	Applications
AHP	Powerful tool applying to make decisions when multiple and conflicting criteria are present, and both qualitative and quantitative aspects of a decision need to be considered	• Easy to implement • Robust • Ability to handle complex problems • Flexibility and intuitive appeal in different problems	• Requiring a large number of evaluations by the DM, especially for large problems • Having long and slow process time • Repetitive process in case of adding new criterion	Automobile castings,Bicycles manufacturing, Semiconductor manufacturing industry, Furniture industry, Airline industry, Printer manufacturing
ANP	Decision finding method and generalization of the analytic hierarchy process allowing for feedback connection and loops	• Ability to cope with non-linear structure • Dealing systematically with all kinds of dependence and feedback in a decision system	• In case of complex decisions, it needs complex methodology • Only suitable for long term strategic decision • Timely and complex pair-wise comparisons	High technology metal-based manufacturing, Electronic industry
DEA	multi-criterial approach which capable of handling multiple inputs and outputs which are expressed in different measurement units	• Capable of handling multiple inputs and outputs • Useful in uncovering relationships that remain hidden for other methodologies	• Results are sensitive to the selection of inputs and outputs (Berg, 2010) • Incapable to provide a test for the best specification	Telecommunications industry, Supply chain management, Electronic components manufacturing, Nuclear power industry, Pharmaceutical industry
MP **LP**	multi-criterial approaches to find the best or optimal solution to a	• Provide proper solution for complex problems • Capable of	• It depends on human judgment in some situation, such as given	Pharmaceutical industry, Telecommunications industry, Personal

	IP	problem that requires a decision or set of decisions about how best to use a set of limited resources to achieve a state goal of objective	optimising results using both single and multiple objective model • Simplicity and easy way of understanding • Makes use of available resources efficient • Adaptive and more flexibility to analyse the problems	weights. • Factors such as uncertainty and time are not taken into consideration	computer manufacturing, Agriculture industry, Hydraulic gear pump manufacturing, Agricultural and construction equipment manufacturing
	GP				

Cebi and Bayraktar (2003) proposed an integrated GP and AHP model including both quantitative and qualitative conflicting factors aims for the food manufacturing industry. The authors argued that food industries need to focus on an effective, systematic and scientific approach to supplier management and supplier selection in order to improve their competitive advantages. There were four main objective functions in the research, maximisation of quality, minimisation of delivery, minimisation of cost, and maximisation of utility function. The AHP method used in order to calculate the coefficients of the utility function (forth objective function) included qualitative criteria except quality, delivery and cost to prevent duplication in the model. Similar work was proposed by Wang *et al.,* (2004, 2005), by integrating AHP and GP based MCDM methodology in automobile manufacturing industry. This research showed the combination of AHP weighting with GP (AHP-GP) is able to offer the best set of multiple suppliers while capacity was set as a constraint. Another research by using AHP-GP model in automobile industry has been proposed by Percin (2006). In order to evaluate the overall scores of alternatives suppliers and to measure the relative importance weightings of potential suppliers, the AHP model is applied emphasizing 20 evaluation criteria. Moreover, all weightings, five objective functions (maximizing suppliers' scores, maximising after-sales service levels , minimizing suppliers' defects rate, minimising rate of late order delivery, minimising purchasing costs) , and constraints are set by using the GP approach. One of the main advantages of this model is its flexibility to quickly respond to changing requirements in the automobile industry and to provide better solutions to decision makers and managers.

For sustainable manufacturing, Gupta *et al.* 2010 developed a hybrid approach using an integrated AHP and fuzzy mathematical programming (AHP-FMP). In order to measure weightings of the various assets (liquid assets, high-yield assets, and less risky assets) within a cluster from the investor's points of view, and to determine suitability of different assets

from a specific cluster for a given investor type, AHP has been used. Moreover, based on the results of the survey in their research and due to using mathematical programming, the authors specified five criteria (short term return, long term return, risk, liquidity and AHP weighted score of suitability). The main advantage of the proposed model is its capability and sustainability for each investor type in manufacturing organisations and also accommodating specific preferences within a given type.

To solve the multi-objective capacitated, multi-facility location problem in global manufacturing, and also to show the way to make better decisions and identify the results of wrong decisions when they received wrong data, Ozgen and Gulsun (2014) proposed an integrated linear programming approach and fuzzy analytical hierarchical process approach. The authors believe that the only way to deal with the imprecision of input data is to integrate two approaches. Minimising the total cost as well as maximising qualitative factor benefits (profit, customer satisfaction, and flexibility and robustness) in a four-stage supply chain network (suppliers, manufacturing plants, distribution centres, and customers) was set as the objective functions.

However, many researchers proposed mixed MP models in manufacturing organizations in order to take advantage of flexibility, control-oriented formulation, and ease of use of different MP models, such as the mixed linear-integer MP model, the integer-GP model, and the linear-GP model.

In order to find an optimised solution for a parallel-machine scheduling problem with sequence-dependent setup times and release dates, Gharehgozli *et al.* (2009) presented a novel, mixed integer-goal programming (MIGP) model. Minimising the total weighted flow time and the total weighted tardiness simultaneously were set as the main two objective functions due to the complication of the model and uncertainty in real-world machinery scheduling. In addition, completion time of a real job assigned to the position in the sequence on any machine and the sequence-dependent set-up time were counted as two main constraints in MIGP model.

Ashouri *et al.* (2013) designed a mixed integer-linear programming (MILP) to optimise energy consumption in buildings. Moreover, authors designed and executed different building services such as thermal and electrical storages, heating and cooling systems, and renewable energy sources by using the proposed MILP model. The main problem in this research was to formalise the optimal selection and the making of modules while minimising the total costs. Hence, the main objective function includes minimising operating, investment, and discomfort objectives. While the operating objective represents the total consumption price of electricity and gas, the investment objective includes all purchasing, installation,

maintenance cost. Furthermore, the limitation of annual CO_2 emissions and energy consumption per square meter of predefined area in building was set as two constraints.

Conclusion

In this paper, a comprehensive and critical overview on the suppliers evaluation and selection is presented and discussed, particularly for the whole manufacturing supply chains and product development life cycle, i.e. from the decision and procurement of the raw materials to the delivery of final goods to the customers. Hence, approaches related to (1) suppliers selection conception and criteria, and (2) suppliers selection methods were thoroughly reviewed. The concepts of supplier selection in manufacturing sectors were discussed with in-depth, followed by a critical analysis of various criteria selection over four time periods, i.e. 'Past to 1966', 'Period of 1966-1991', 'Period of 1991-2001', and '2001 to present'. In addition, different types of suppliers selection methods, their particular advantages and limitations have been discussed in details, which is taken as a part of this research. This research overview is managed to identify the most appropriate suppliers selection method and intrinsic selection decision-makings in the process. Individual methods such as Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Mathematical Programming (MP), Data Envelopment Analysis (DEA), Goal Programming GP), Linear Programming (LP), and Integer Programming (IP) were reviewed comprehensively and then followed by integrated (mixed) methods in a comparative analysis manner. The comparative study and analysis has also sheded the light for future development in the subject domain to some extent.

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