Supplier selection criteria and methods: past, present and future

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Abstract: Sole purpose of supplier selection is not limited to get supply at low cost and at right time. Supplier selection is a strategic decision to fulfil company's goal for long period of time at low risk. To accomplish this objective companies are moving from reactive buying to proactive buying to give more priority to co-creation of wealth with supplier/s. Considering this issue an attempt has been made in this paper to give systematic review of supplier selection and evaluation process from 2005 to 2012 to answer three main questions: (i) Which method is more appropriate for supplier selection? (ii) Which evaluating criteria were most cited? (iii) Is present trend of research is adequate enough to support proactive buying? In this regard, 78 papers are classified into 10 categories to identify factors affecting supplier selection and evaluation process. Statistical analysis has been conducted with software "**R**" to have better insight on the trend of research. Recommendations and future work is also included to verify inadequacy of existing methods, if any, to support proactive buying process.

Keywords: *Proactive supplier selection; Decision support system; Multi-criteria decision making tools; Statistical analysis; Review.*

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customisation. His biography is also selected by Marquis Who's Who in 2014. He is the member of DSI,USA; ISM,USA; EUROMA; EURO SC Group etc.

1 Introduction

"The objectives of the purchasing function are that it should obtain the right materials (meeting quality requirements), in the right quantity, for delivery at the right time and right place from the right source (a supplier who is reliable and will meet its commitments in a timely fashion), with the right service (both before sale and after sale), and at the right price." (Gaither, 1996 as cited in Moynihan et al. 2006).

Jabil Circuit Inc. one of the largest companies in the Tampa Bay area survived from the disruption of supply chain due to 2011 Tōhoku earthquake and Tsunami in Japan for its effective strategy and the co-operation of its suppliers. In 2012, Japanese car makers faced supply shockwave due to severe flood at the low-lying areas of Ayutthaya and Pathumthani provinces of Thailand where vast majority of suppliers are located. Success of Jabil Circuit Inc. proves that behind every great success of any company there was an even bigger supplier and logistician. Any disruption in upstream supply may cause tremendous disaster in entire supply chain and compel organization to take risk. Risks in supply chain are broadly classified as internal risk that appears in normal operation and external risk that come from outside the supply. Selection of right supplier/s could minimize external risks. Supplier selection could be either single sourcing where only one supplier is selected to fulfil the entire demand or multiple sourcing where a group of suppliers are selected to fulfil the need of entire demand. Risk in supply chain could be minimized by internal integration and external integration of supply chain entities. External integration strongly encourages single sourcing by establishing long-term relationship between supplier and organization. Today companies are more interested about proactive buying instead of reactive buying. Reactive buying gives highest priority to cost and restrict sharing of knowledge and information. Proactive buying considers procurement as main management function. In proactive buying, suppliers are not only selected on lowest cost basis rather on various strategic issues to fulfil long term goal of any company. Proactive procurement prefers multiple sourcing to have better negotiation options and encourages sharing of knowledge and information i.e. co-creation of wealth. In this regard a comparative analysis of single and multiple sourcing is conducted initially to show various advantages of both processes, shown in table 1.

Table 1 Single sourcing versus multiple sourcing.

Single sourcing	Multiple sourcing
Concept of this strategy comes from just in-time (JIT) philosophy. Uncertainty in supply is very high as buyer deals with single supplier.	Multiple sourcing is preferable if reliability of one supplier is very poor. It reduces safety stock without increasing stock out problem (Kelle and silver, 1990).It reduces uncertainty in supply but increases the fixed cost associated with operating multiple suppliers (Agrawal and Nahmias,1997)
No competition exists as only one supplier is involved. It gives quantity discount from order consolidation, reduce order lead time and logistical lead time (Hahn et al.,1986;Bozarth et al.,1998)	Reduction of price is achieved through competition between suppliers. It gives greater assurance of timely delivery and greater upside volume flexibility (Ramasesh et al., 1991).
It is applicable where goodwill trust exists between buyer and supplier.	In presence of low ordering cost and highly variable lead-times dual sourcing is better than single sourcing (Ramasesh et al., 1991).
Low threat to loss of information.	Since business data is shared among various suppliers, proper security measures should be taken.

Literature review shows rich collection of work on supplier selection. Researchers used various methods such as analytic hierarchy process (AHP), multi objective programming (MOP), data envelopment analysis (DEA), mixed integer programming (MIP), goal programming (GP), genetic algorithm (GA), analytic network process (ANP), case based reasoning (CBR), data mining (DM), cluster analysis (CA), activity based costing (ABC),technique for order preference by similarity to ideal solution(TOPSIS), rough sets theory (RST), quality function deployment (QFD), neural network (NN), multi attribute utility theory (MAUT). Some researchers combined at least two of the above technique for supplier selection. For instance, AHP-GP, AHP-LP, DEA-AHP, DEA-MOP etc. In this regard, table 2 shows various techniques for single sourcing and multiple sourcing supplier selection.

Table 2 Various techniques for single sourcing and multi sourcing supplier selection

Single sourcing			Multi sourcing	
Sl. No.	Methods	Remark	Sl. No.	Methods
1.	Linear	Depends heavily on	1.	Mixed integer programming.

	weighted point	human judgments.		
2.	Categorical method	Depends heavily on human judgments.	2.	Goal programming.
3.	Cost ratio	Very complicated and need more financial information.	3.	Single/ multi objective programming.
4.	AHP	More accurate than any other method (Ghodsypour and O'Brien,1998)	4.	Multi attribute utility theory and AHP; AHP-LP; AHP-GA; AHP and multi-objective possibilistic linear programming (AHP-MOPLP) etc.

This paper is organized as follows: section 2 covers extensive literature review with detail statistical analysis, section 3 gives recommendations to improve existing supplier selection methods and section 4 concludes the paper.

2 Literature review and statistical analysis

Research work related to supplier selection is considerably very high. For instance, from www.sciencedirect.com alone 13,201 articles were found with the search word "supplier selection" for publication 2009 onwards. In this regard, about 78 papers are selected from peer review journals from 2005 to 2012. Papers are selected based on the reputation of journal and citation of papers. Some papers from other journals are also considered because of their rich content. Related articles on supplier selection are grouped and broadly classified into 10 categories, shown in table 3.

Table 3 Classification of research work

Sl.No.	Classification of research work	Author/s
1	Supplier selection for single item or multiple items under stochastic demand and/ supply	Guan et al.; Bilsel and Ravindran ;
2	Supplier selection for manufacturing industry	van der Rhee et al. ; Ustun and Demirtas;
3	Supplier selection for electronics industry	Yu and Tsai; Amin and Razmi; Lee et al.; Önüt et al.
4	Supplier selection under price break with or without volume discount	Amid et al.; Xia and Wu; Kokangul and Susuz; Che and Wang
5	Decision support system (DSS) for supplier selection	Cakir and Canbolat
6	Supplier selection for green supply chain	Hsu andHu; Shaw et al.; Tate et al.;

7	Supplier selection for new product development	Kim and Wagner
8	Supplier selection for customized system	Sawik, T.
9	Supplier selection by various techniques	Faez et al.; Li et al.; Chan and Kumar; Wu,M.; Lin, R.-H.; Wang et al.; Hong and Ha; Levary, R.R.
10	Strategic supplier selection	Huang and Keskar; Wang et al.

Review shows that majority of the work is related to the development of various methods for supplier selection. In this paper, literature survey is conducted to find the followings:

1. To identify most cited criteria for supplier selection.
2. To identify different methods for supplier selection.
3. To identify the trend of supplier selection methods.
4. To check the adequacy of present trend for proactive buying.
5. To identify all journals where research work related to supplier selection is published frequently.
6. To identify countries, based on frequency of publication as the most promising place for supplier selection researchers.

Study shows that supplier selection methods can be broadly categorized into two category-single model and integrated model, shown in fig 1.

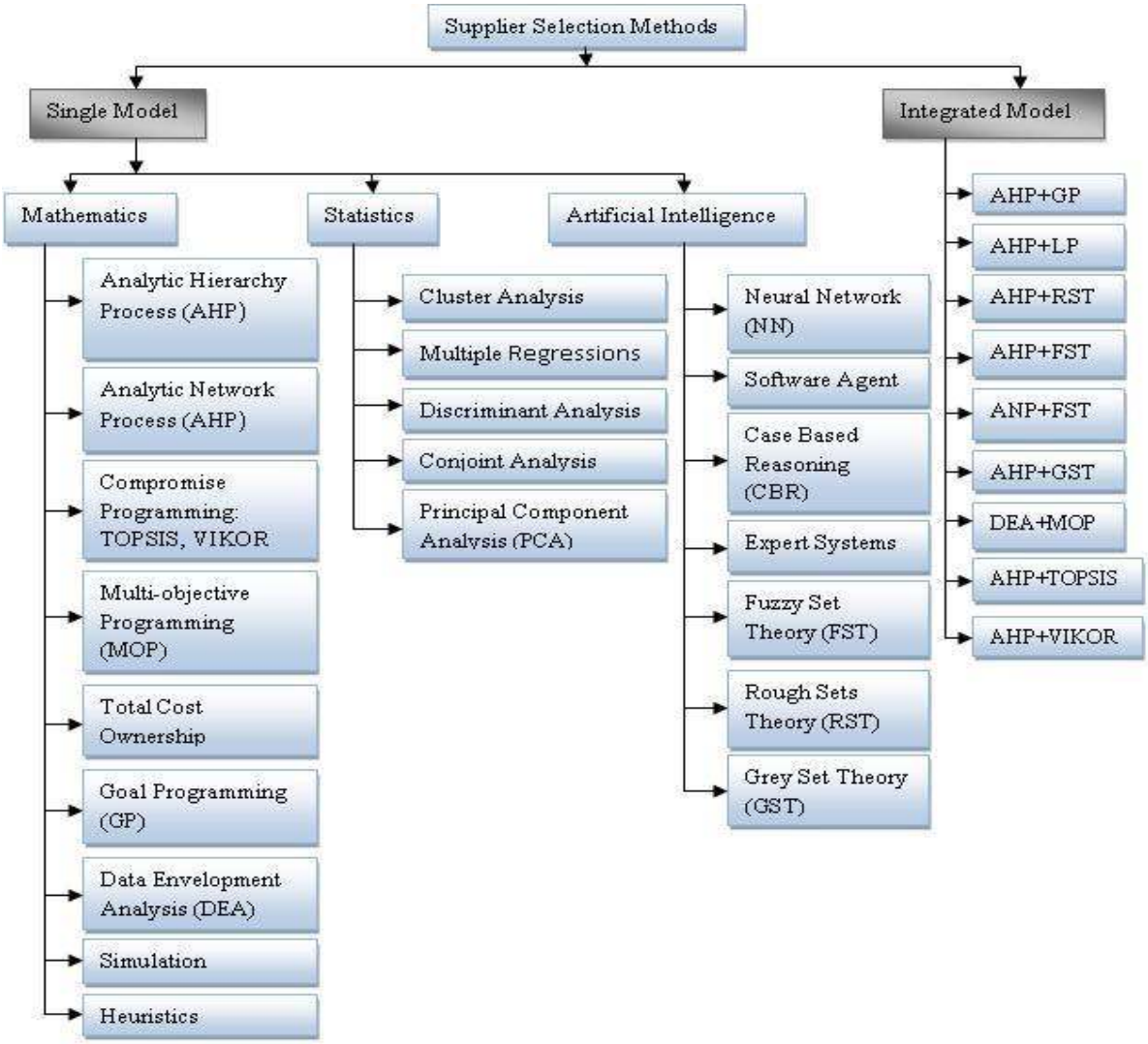

Fig. 1 Classification supplier selection methods (Source: Mukherjee et al.)

Among all methods- analytic hierarchy process (AHP), analytic network process (ANP) and their integrated model is mostly used by various researchers, shown in fig.2. AHP and the integrated method of AHP is most cited method for supplier selection. Moreover, this study reveals that present research trend on supplier selection gives more emphasizes on multiple suppliers selection instead of single supplier selection, shown in fig.3.As shown in Fig.1, mathematical, statistical or artificial intelligence

(AI) could be used for single sourcing as well multiple sourcing. Integrated models usually combined with linear program (LP), genetic algorithm (GA) or particle swarm optimization (PSO) to allocate order among multiple suppliers. Among several criteria-cost, quality, delivery and service are mostly cited by various researchers, shown in table 4. However, different researchers used same criterion with different terminology, ex. delivery time, on-time delivery, delivery reliability etc. Table 5 shows different methods proposed by various researchers for electronics industry, automobile industry, manufacturing industry, textile industry etc.

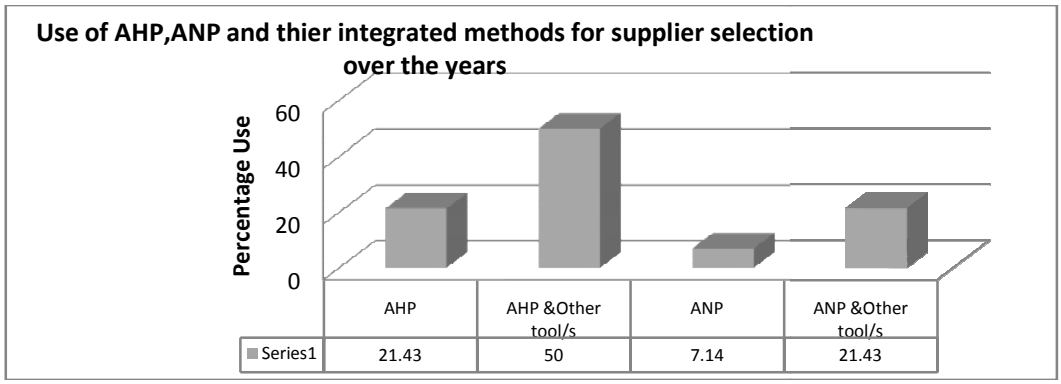

Fig.2 Use of AHP, ANP and their integrated approach (Source: Mukherjee et al.)

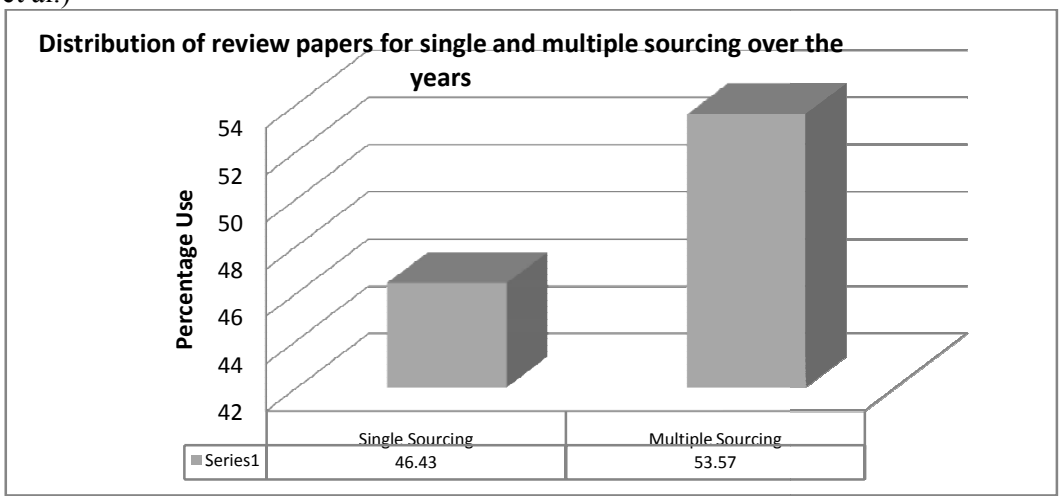

Fig.3 Distribution of review papers for single and multiple sourcing (Source: Mukherjee et al.)

Table 4 Supplier selection criteria

Year	Author/s \ Criteria	Cost	Quality	Delivery	Service	Supplier's Profile	Reliability	Environment	Responsiveness	Logistical Performance	Commercial Plans & Structure	Production	Facility and Technology	Professionalism of Salesperson	Quality of Relationship with Vendor	Risk Factor	Technology and Capability	Mutual Trust & Easy Communication	Collaboration	Annual Demand	Availability	Supplier's Willingness	R & D
2005	Ozden Bayazit and Birsen Karpak									x	x	x											
2006	Huan-Jyh Shyur and Hsu-Shih Shih	x	x	x					x				x	x	x								
2007	FU Yao and LIU Hongli	x	x	x		x																	
2007	Felix T.S. Chan and Niraj Kumar	x	x		x	x										x							
2007	Weijun Xia and ZhimingWu	x	x		x																		
2007	Min Wu	x	x	x	x	x											x						
2007	Sanjay Jharkharia and Ravi Shankar	x	x			x											x						
2007	Cevriye Gencer and Didem Gu¨rpinar		x			x											x						
2007	Ezgi Aktar Demirtas and Ozden Ustun	x	x	x	x	x											x	x					
2008	Ali Kokangul and Zeynep Susuz	x		x													x		x				
2008	Wang et al.	x	x		x																		
2008	Reuven R. Levary						x									x							
2008	Jing-Rung Yu and Chao-Chia Tsai	x	x	x	x			x															
2008	Ozan Cakir and Mustafa S. Canbolat	x	x																	x	x		
2008	Sung Ho Ha and Ramayya Krishnan										x						x	x					
2008	Amy H.I. Lee	x	x	x												x							
2008	Eleonora Bottani and Antonio Rizzi																x	x				x	
2008	Rong-Ho Lin	x	x	x													x						
2008	Semih Önüt, Selin Soner Kara, and Elif Is_ik	x	x	x																			
2008	Ozden Ustun and Ezgi Aktar Dem˙ırtas	x	x	x	x	x											x	x					
2008	Wann-Yih Wu et al.	x	x																				
2009	Chia-Wei Hsu and Allen H. Hu		x								x												x

Table 5 Review of supplier selection methods from 2005 to 2012

Method	Year	Author/s
Mathematics		
AHP	2005	Bayazit and Karpak
AHP	2007	Yao and Hongli
AHP	2008	Reuven R. Levary
AHP	2012	Bruno et al.
AHP	2012	Parthiban et al.
ANP	2007	Gencer and Gu¨rpinar
ANP	2009	Hsu and Hu
GA	2008	Che and Wang
PSO	2006	Mouli et al.
Multi-objective chance constrained programming	2011	Bilsel and Ravindran
Stochastic mixed-integer programming	2011	Tadeusz Sawik
Integer linear programming	2012	Choudhary and Shankar
Statistics		
Multiple Analysis of Variance	2012	Riedl et al.
Discrete choice analysis (DCA)	2008	Van der Rhee, B., et al.
Descriptive Statistics, ANOVA etc	2012	Jin Wang
Artificial Intelligence		
Vague set	2008	Zhang et al
2-tuple linguistic computing	2010	Wen-Pai Wang
Integrated Model		
F-AHP and GA	2006	Kubat and Yuce
AHP,QFD and PGP	2006	Sarfaraz and Balu
Fuzzy AHP TOPSIS	2006	Chen et al.
AHP and proportional rule	2007	Che et al.
CBR, AHP, Fuzzy Set and mixed integer programming	2007	Fayez et al.
Fuzzy extended AHP	2007	Chan and Kumar
AHP, rough set and multi-objective mixed integer programming	2007	Xia and Wu
TOPSIS-AHP simulation	2007	Min Wu
AHP and multi-objective non-linear integer programming	2008	Kokangul and Susuz
AHP and integer programming	2008	Yu and Tsai
AHP,DEA or NN	2008	Ha and Krishnan
FAHP and fuzzy multiple goal programming	2008	Lee et al.
FAHP and fuzzy multiple goal programming	2008	Amy H.I. Lee
Cluster analysis, fuzzy logic and AHP	2008	Bottani and Rizzi
Fuzzy set, interpretive structural modeling(ISM) and AHP	2008	Yang et al.
FAHP and fuzzy multiple goal	2009	Amy H.I. Lee

programming		
AHP and Goal programming	2012	Erdem and Göçen
F-AHP and Fuzzy Linear programming	2012	Shaw et al.
NGT ,ANP and TOPSIS	2006	Shyura and Shih
ANP and Archimedean Goal Programming (AGP)	2007	Demirtas and Ustun
FANP-MOLP	2008	Rong-Ho Lin
Delphi and ANP	2008	Wu et al.
Fuzzy ANP and fuzzy TOPSIS	2008	Önüt et al.
ANP and multi-objective mixed integer LP	2008	Ustun and Dem˙ırtas
Delphi , ANP and MIP	2009	Wu et al.
Data mining and mixed integer programming.	2005	Hong et al.
Supplier capability and price analysis chart is prepared based on price index and supplier process performance.	2005	Chen et al.
Imprecise data envelopment analysis (IDEA)	2007	Reza Farzipoor Saen
Fuzzy C-means algorithm and PSO	2007	Mehdizadeh and Moghaddam
Fuzzy rough set and GA	2007	Guo et al.
Various configurable matrices for supplier selection is discussed	2007	Huang and Keskar
Fuzzy weighted average and multi-objective mixed integer LP	2007	Amid et al.
Grey theory and multi-attribute decision making.	2007	Li et al.
Multi-objective mixed integer stochastic programming	2007	Guan et al.
Fuzzy NN , GA and principal component analysis (PCA)	2008	Moghadam et al.
Fuzzy hierarchical TOPSIS	2008	Wang et al.
Machine learning & MCDM	2008	Hong and Ha
Fuzzy TOPSIS and mixed integer programming	2008	Lin and Chang
Weighted LP	2008	Wan Lung Ng
Fuzzy set theory and QFD	2008	Amin and Razmi
Fuzzy SMART	2008	Chou and Chang
Simulation of CCP,MOP,DEA	2008	Wu and Olson
Fuzzy linguistic quantifier with order weighted aggregation	2009	Wang et al.
Possibility fuzzy multi-objective programming	2010	Wu et al.
Fuzzy set theory and VIKOR	2010	Sanayei et al.
Bi-objective mixed integer programming	2010	Tadeusz Sawik
A weighted max-min multi-objective model	2011	Amid et al.
Fuzzy TOPSIS and 2-stage stochastic programming	2011	Selin Soner Kara
Fuzzy set and Grey theory	2012	Mukherjee and Kar

Table 6 Statistical analysis of distribution of research papers from 2005 to 2012

Data Analysis					
Mathematics	**Statistics**	**Artificial Intelligence**	**Integrated Method**	**Skewness**	**Kurtosis**
12	3	2	50	1.025	2.217
Integrated Method					
Integrated AHP	**Integrated ANP**	**Others**	**Skewness**	**Kurtosis**	
18	7	25	-0.2641	1.5	

Statistical analysis has been conducted with software "R" to find trend of research. As shown in table 6, among four different methods researchers are keen to use integrated method as skewness is positive, i.e. 1.025. Among different integrated methods researchers are more interested about the use of integrated AHP as skewness is negative, i.e. -0.2641. Obtained kurtosis value in both cases is less than 3. Therefore both distributions follows platykurtic curve which is less peaked than normal curve. Simplicity and effectiveness of AHP could be the expected reason for its extensive use.

Supplier selection process is product specific and industry specific. Review shows that more attention is paid to electronics industry, shown in fig. 6. Short product life cycle, advanced manufacturing process, complexity of design and manufacturing process could be the possible reason to demand more effective and robust supplier selection for electronics industry. However, very limited no of articles are found related to supplier selection for mass customized system. Although companies like Dell, BMW, Nike etc are extensively using the concept of mass customization such as assembly-to-order (ATO), build-to-order (BTO), engineer-to-order (ETO) etc. Strategies of mass customization demand proactive supplier selection instead of reactive supplier selection. Present trend of research is adequate and applicable for proactive buying with little modification. For instance, among all criteria for supplier selection more priority should be given to supplier's willingness, mutual trust of buyer and seller, technical capability of suppliers etc. Proactive buying demands multiple sourcing and considers sourcing as strategic sourcing. Present trend also gives more emphasizes on multiple suppliers selection. Thus present methods can be used by considering all strategic issues of procurement so that every procurement could add value to business. More research works are highly expected to develop effective supplier selection methods for such complex and advanced manufacturing system.

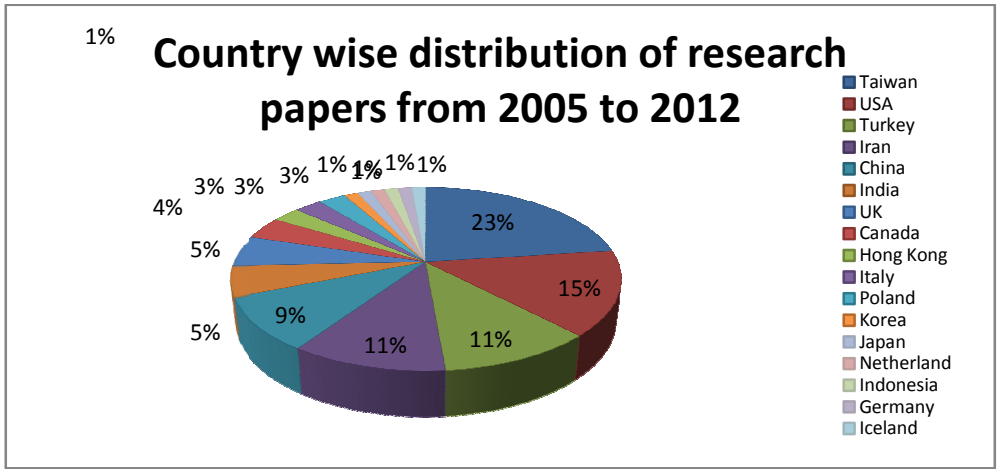

Fig. 4 Country wise distribution of review papers from 2005 to 2012

As shown in fig. 4, major contribution in research related to supplier selection is obtained from Taiwan, USA, Turkey, Iran and China. There cumulative work related is about 69 percent of total research work. In this regard, India and UK both occupies same position. 57 percent of total research work related to supplier selection comes from Expert Systems with Application (ESWA), International Journal of Production Economics (IJPE) and Computers and Industrial Engineering (CIE). Contribution of other journals is also significant, shown in fig.5.

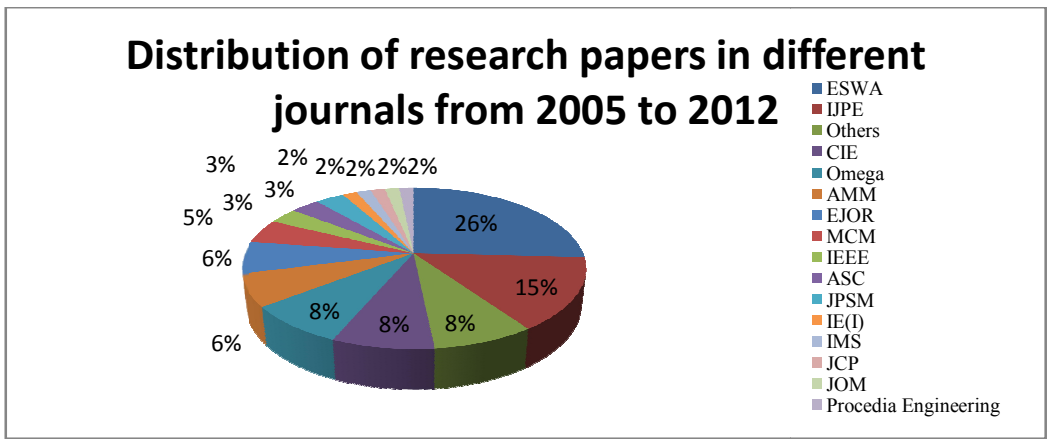

Fig. 5 Distribution of research papers in different journals from 2005 to 2012

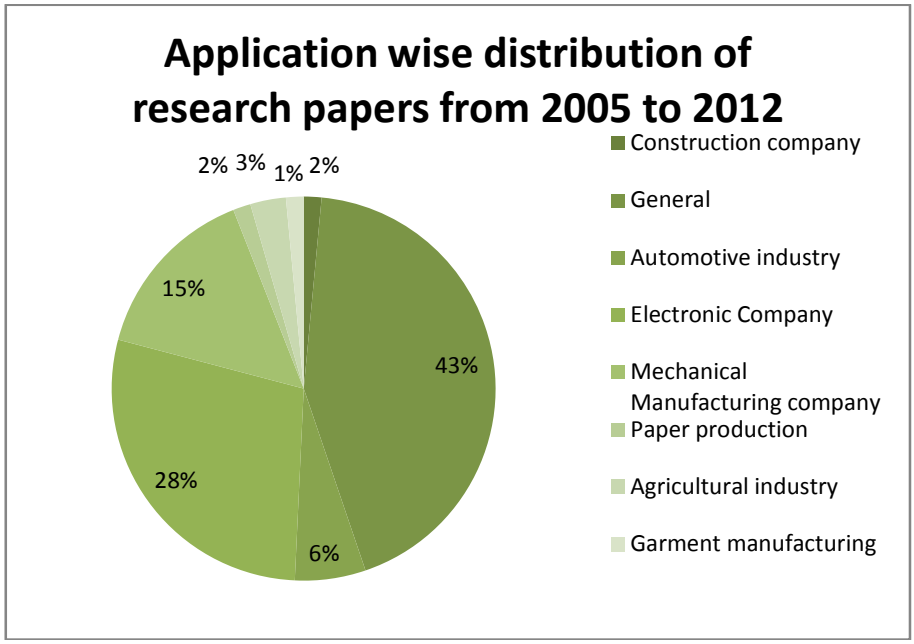

Fig.6 Application wise distribution of research papers from 2005 to 2012.

3. Major observations and recommendations

Majority of research papers used multi-criteria decision analysis (MCDA) tools for supplier selection process to trade off palpable and non-palpable criteria. Therefore, it is pertinent to verify the usability of MCDA tools for supplier selection. Classical MCDA tools are not suitable to deal uncertainties. Fuzzy version of MCDA tools is used for long in this regard. But fuzzy version can't deal all type of uncertainties. It is quite suitable for imprecision and vagueness. Moreover, selection of appropriate fuzzy number is highly subjective and contextual. A more defined framework is quite expected in this regard to select best membership for fuzzification of classical MCDA tools. Very recently two methods got attention to deal uncertainty – Cloud and D-number. Either of them can be used with MCDA tools to deal uncertainties of supplier selection.

Time complexity and rank reversal problem are the main limitations of classical MCDA tools. Rank of existing alternatives may change due to the introduction of new alternative. Rank reversal problem can be avoided by appropriate selection of normalization method. Fuzzification of MCDA tools can't guaranty to generate better solution. Rather it can spoil

existing algorithm by increasing computational time. Unfortunately, very limited researchers justified the use of MCDA tools for specific supplier selection problem in their paper.

Finally, decision of any decision maker is always subjective. Same decision maker can give different decision to same problem under different situation. To achieve consensus group decision making, brain storming etc are highly advisable. Naturalistic decision making process can also be used with MCDA tools to improve decision making process. Naturalistic decision making (NDM) is commonly used for very complex situation and it is not used much for supplier selection. Interested readers can refer relevant papers in this regard.

3.1 Factors affecting proactive supplier selection process

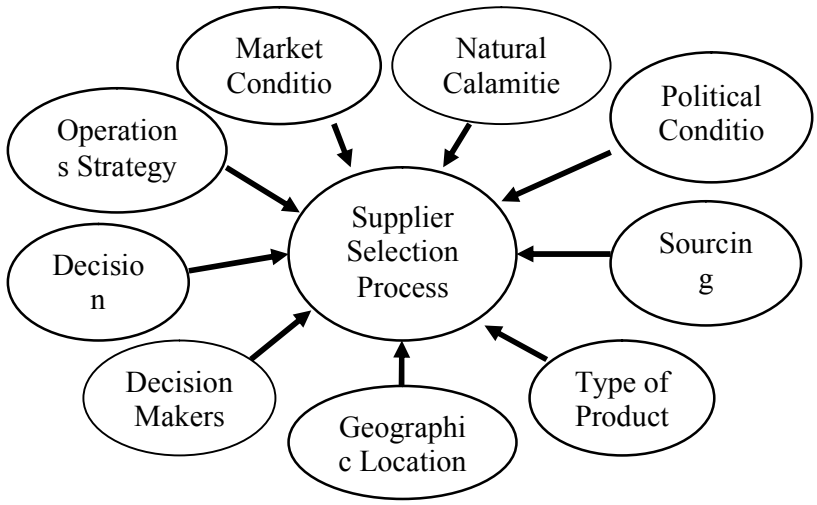

Fig. 7 Factors affecting proactive supplier selection process

Supplier selection process is always influenced by demand side and supply side uncertainties. Volatile market condition brings demand uncertainties and compels decision makers to go for stochastic supplier selection process instead of deterministic supplier selection process. Still such uncertainties are controllable. Uncertainties brought by natural calamities are often uncontrollable in nature, ex., supply shockwave created for Japanese carmakers due to severe flood in Thailand. Like natural disasters, political conditions can cause supply chain disruption and thereby affect

supplier selection process. Type of product, complexity of design and availability of material usually brings supply side uncertainties. All such uncertainties are expected to be prevented, if not completely, by operations and sourcing strategy. Such strategies are geographic location specific. For instance, IKEA, the largest furniture manufacturer, fails to maintain market share in China as they used same strategy for US and China. Finally, supplier selection process is highly influenced by decision maker's choice and selection criteria. It is expected that if all factors shown in fig.7 are controlled effectively then every procurement will add value to business.

3.2 Modification of order allocation model

Literature review shows that supplier selection and order allocation is a two stage problem. In first stage, suppliers are evaluated and selected from supply base by MCDA tools w.r.t some predefined criteria. In the second stage, orders are allocated to selected suppliers by a mathematical model. Single sourcing does not require the second stage as total demand is fulfilled by one supplier. Order allocation stage is important for proactive supplier selection. Order allocation is basically an optimization problem and can be broadly classified as single objective optimization and multiple objective optimizations. Single objective optimization gives equal priority to all constraints. Therefore, it is better to use multiple objective optimization instead of single objective optimization. Usually, objective functions for order allocation are linear weighted functions. Such as total cost of purchase (TCP), total value of purchase (TVP) etc. Usually, TCP is minimized and TVP is maximized with respect to some constraints – quality, late delivery etc (Ghodsypour and O'Brien,2001; Ustun and Demirtas, 2008). The most important constraints for any supplier selection problems are supplier capacity, minimum order quantity to fulfill demand, and cost or budgetary limitations (M.Kumar et al.,2004; Ghodsypour and O'Brien,1998). TVP can maximize value but can't guaranty reliability of purchase to reduce the impact of supply chain disruption. Therefore, total valuable of purchase (TVP) should be modified as total value of reliable purchase (TVRP) to consider reliability of each selected suppliers during order allocation (Mukherjee et al.,2013). It should be one of the central criteria for proactive buying as proactive buying avoids defective supplies. Finally, in majority of order allocation problem price or cost of each product is considered as constant. It may not be the case of real life problem. Cost could be the function of quantity. Hence, it is better to use

non-linear weighted order allocation problem instead of linear weighted order allocation problem.

4. Conclusions

Proactive supplier selection is a multi-criteria decision based optimization problem. It is a strategic process as judicious selection of supplier brings seed of success to company. To survive in heterogeneous volatile market an effective supplier selection method is highly required for any company. In this paper, it was found that present trend of supplier selection is integrated or hybrid approach of two or more methods. Second, it was observed that AHP and their integrated methods are most preferred among researchers. Third, it was shown that multiple sourcing is much preferred than single sourcing. Fourth, it was observed that cost, quality, delivery and service are the most cited criteria for supplier selection. It was also observed that different researchers used different name for same or almost same criteria. Hence, taxonomy is required to name various criteria for supplier selection. Fifth, present trend is adequate for proactive buying. However, little modification is required for supplier selection criteria to give more priority to supplier's willingness, mutual trust of buyer and seller etc. Finally, it was mentioned that total value of purchase (TVP) should be replaced by total value of reliable purchase (TVRP) to reduce inbound supply chain risk. In this regard several factors are identified and recommendations are mentioned to aid practitioners and decision makers to solve supplier selection problem effectively.

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