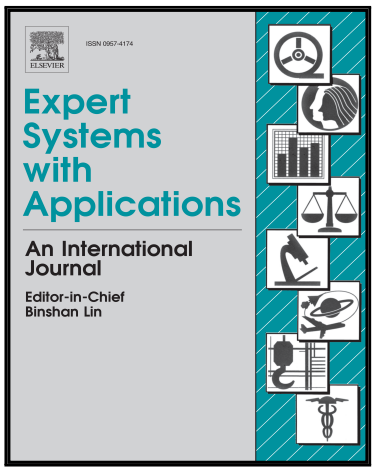

Designing an integrated AHP based decision support system for supplier selection in automotive industry

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Highlights

- AHP applied to decision making of automotive industry supplier selection
- Use of AHP in supplier selection gives decision maker confidence of consistency
- Sensitivity analysis to check the robustness of the supplier selection decision
- Proposed approach divides complex decision making into simpler hierarchy

Designing an integrated AHP based decision support system for supplier selection in automotive industry

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Abstract

Purpose: The purpose of this paper is to propose a decision support model for supplier selection based on analytic hierarchy process (AHP) using a case of

automotive industry in a developing country of Pakistan and further performs sensitivity analysis to check the robustness of the supplier selection decision.

Methodology: The model starts by identifying the main criteria (price, quality, delivery and service) using literature review and ranking the main criteria based on experts' opinions using AHP. The second stage in the adopted methodology is the identification of sub criteria and ranking them on the basis of main criteria. Lastly perform sensitivity analysis to check the robustness of the decision using Expert Choice™ software.

Findings: The suppliers are selected and ranked based on sub criteria. Sensitivity analysis suggests the effects of changes in the main criteria on the suppliers ranking. The use of AHP in the supplier selection gives the decision maker the confidence of the consistency and the robustness throughout the process.

Practical implications: The AHP methodology adopted in this study provides managers in automotive industry in Pakistan with the insights of the various factors that need to be considered while selecting suppliers for their organizations. The selected approach also aids them in prioritizing the criterion. Managers can utilize the hierarchical structure of adopted supplier selection methodology suggested in this study to rank the suppliers on the basis of various factors/criteria.

Originality/value: This study makes three novel contributions in supplier selection area. First, AHP is applied to automotive industry and use of AHP in the supplier selection gives decision maker the confidence of the consistency. Second, sensitivity analysis enables in understanding the effects of changes in the main criteria on the suppliers ranking and help decision maker to check the robustness throughout the process. Last, we find it important to come with a simple methodology for managers of automotive industry so that they can select the best suppliers. Moreover, this approach will also help managers in dividing the complex decision making problem into simpler hierarchy.

Keywords: Supplier Selection, Analytic Hierarchy Process (AHP), Supply Chain Management, Multi-Criteria Decision Making (MCDM), Sensitivity Analysis, Decision Support System.

1. Introduction

Supplier selection is one of the strategic decision that companies have to take and are vital as they play significant role in overall supply chain management. It is a multi-criteria decision making (MCDM) problem. In addition, supplier selection in today's competitive market is the most critical function for the success of overall performance of supply chain cycle and organization. The present study focuses on building a decision support system for supplier selection strategy using Analytic Hierarchy Process (AHP) based on a case study of automotive sector in Pakistan.

1.1 Automobile Industry in Pakistan

According to Beşkese and Şakra (2010), the automotive industry is the principle customer for many industrial branches such as iron and steel, light metals, petro-chemicals, glass, tires, etc. Moreover, it creates vast business volume and employment together with its suppliers as well as the auxiliary sectors of marketing, distribution, services, fuel, finance and insurance which supply automotive products/services to customers. That's why automotive industry is considered as a backbone of any industrialized nation and developing country like Pakistan.

The Automotive industry has been an active and growing field in Pakistan for a long time, however not large enough to be in the prominent list of the top automotive industries, having a stable annual production 100-170 thousand automobiles only. Currently some of the major world automakers have set up assembly plants or are in joint ventures with local companies including Toyota, General Motors, Honda, Suzuki, and Nissan. The total contribution of Auto industry to GDP in 2012 was 2.8% which is likely to increase up to 5.6% in the next 5 years. Auto sector presently, contributes 16% to the manufacturing sector which is predicted to increase 25% in the next 7 years (Hanif, 2012).

After the first produced vehicle in 1953, the journey of auto industry has been rough, tough and sometime very smooth till 2012. Car industry saw boom in 2006-2007 when sales touched record peak of 180,834, the car industry has invested over Rs 20 billion in the last four to five years to meet growing demand. The direct employment in car industry hovers between 5,500-6,000 workers. Motorcycle production hit the country's record level of over 1.5 million units in 2010-2011. Auto sector now employs 192,000 people directly and around 1.2 million indirectly and has Rs 98 billion of investments and contributes Rs 63 billion as indirect tax in the national exchequer. Auto Sector remains the second largest payer of indirect taxes after the Petroleum Sector in Pakistan (Hanif, 2012).

Pakistan Auto Industry Development Program (AIDP-2006), a study conducted by Ministry of Industries and Production, Government of Pakistan states that the Pakistan Auto Industry has become a leading industrial sector to steer the growth in large scale manufacturing sector. The report further elaborates that Pakistan is amongst a few countries of the world which manufacture all kinds of vehicles i.e. 2/3 wheelers, motorcars, LCVs, tractors, prime-movers &trucks and buses. The total country requirements are generally met from the local production except the import of certain categories of trucks and prime-movers.

As already alluded to, the automotive sector is the second largest sector in Pakistan and a lot of local parts manufacturers or suppliers are there and fulfilling the automotive manufacturer needs and demands. Moreover, local suppliers are key for the country's economic growth (since it is second largest tax payer sector) and a proper section of supplier is must for success. Since this country's economy depends on automotive sectors, so the job of buyer or procurement professionals are not only important but challenging as well. They should identify, define and measure what is best for the company and execute procurement decisions accordingly. In order to identify what is best for the company, supplier selection and its associated criteria selection will play an important role.

1.2 Supplier Selection

Supplier selection criteria depends on various factors such as quality of product, price, delivery, financial measures, technical collaboration, company structures, quality systems and supplier experience and its reputation. These major criteria are composed of sub-criteria that may also affect the evaluation of the system. Some companies may have fewer criteria or sub-criteria than others based on experience or maturity level of the company's purchasing system and the availability of data. These criteria and their sub-criteria can be identified through literature review. The weight (effect) of each criteria and sub-criteria will be determined by soliciting experts' opinions through a survey of experts. The purpose of this survey is only to enumerate the critical success factors that will form the basis to identify the specific criteria and sub-criteria to formulate the AHP model.

1.3 Analytical hierarchy process

AHP is a common multi-criteria decision making method .It is developed by Saaty to assist in solving complex decision problems by capturing both subjective and objective evaluation measures. It breaks a complex problem into hierarchy or levels as shown in Figure 1 below.

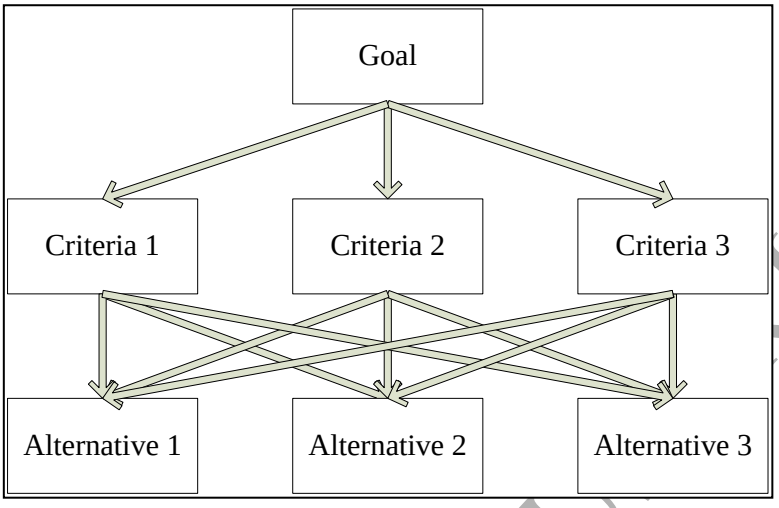

Figure 1. AHP Structure (Adopted from Khan *et al*. 2016)

AHP uses a pair-wise comparison of the criteria importance with respect to the goal. This pair wise comparison allows finding the relative weight of the criteria with respect to the main goal. If quantitative data is available, the comparisons can be easily performed based on a defined scale or ratio and this cause the inconsistency of the judgment will be equal to zero which leads to perfect judgment.

If quantitative data is not available, a qualitative judgment can be used for a pair wise comparison. This qualitative pair wise comparison follows the importance scale suggested by Saaty (1980) as shown in Table 1.

Table 1: Importance scale of factors in pair-wise comparison

Importance Scale	**Importance Description**
1	Equal Importance of "i" and " j"
3	Week Importance of " i" over " j"
5	Strong Importance of " i" over " j"
7	Demonstrated Importance of " i" over " j"
9	Absolute Importance of " i" over " j"
Note: 2, 4, 6 and 8 are intermediate values.	

The same process of pair-wise comparison is used to find the relative importance of the alternatives with respect to each of the criteria.

Each child has a local (immediate) and global priority (weight) with respect to the parent. The sum of priorities for all the children of the parents must equal 1. The global priority shows the alternatives relative importance with respect to the main goal of the model. The pair-wise comparison is performed in matrix format to check the consistency of the judgment.

The size of the comparison matrix (**A**) is n x n where n is the number of children (criteria or alternatives) being compared with relative to a specific parent (goal or the criteria). The elements of the matrix are a_{ij}. The matrix **A** is considered consistent if all of its elements are transitive and reciprocative such as

$$a_{ij} = a_{ik} \times a_{jk}$$

$$a_{ij} = 1 / a_{jk}$$

Where i, j and k are any elements of the matrix **A**.

$$\mathbf{A} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix}$$

Where $a_{ij} = 1$ when i=j

To check for consistency, an **N** matrix is computed where **N** is the normalized matrix of **A**.

$$\mathbf{N} = \begin{pmatrix} w_{11} & w_{12} & w_{13} \\ w_{21} & w_{22} & w_{23} \\ w_{31} & w_{32} & w_{33} \end{pmatrix}$$

Where, $w_{ij} = a_{ij}$

$$w_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}$$

$\sum_{i=1}^{n} a_{ij}$ is the sum of the columns

Then we have to find relative weight of each row by dividing the sum of the values of each row of n.

$$\text{Weight of i} = w_i = \frac{\sum_{j=1}^{n} w_{ij}}{n}$$

Notice that $\sum_{i=1}^{n} w_i = 1$

Notice that **A** is considered consistent if **A x w** = n x **w**

This equation is treated as an Eigenvalue problem. It is safe to assume according to Saaty that the largest Eigenvalue is greater than or equal to n ($\lambda_{max} \geq n$), The closer λ_{max} to n, the more consistent is **A**. λ_{max} is equal to the sum of the elements of the column vector **AW**.

The consistency ratio (CR) is calculated by AHP as

$$CR = \frac{CI}{RI} = \frac{Consistency\ Index}{Random\ Consistancy\ of\ A}$$

$$\text{Where} \quad CI = \frac{\lambda max - n}{n-1}$$

$$RI = \frac{1.98\ (n-2)}{n}$$

If $CR \leq 0.10$, the level of inconsistency is considered acceptable. Otherwise, the decision maker needs to revise the judgment on the values of a_{ij}.

In section 2, an extensive literature review of supplier selection; its importance, criteria and methodology is presented. Then in section 3, methodology of applying AHP based decision support system in the case of Pakistan's automotive industry supplier selection is presented using real data through soliciting into selection via survey of experts. Sensitivity analysis of the results is presented in section 4. Managerial implications are offered in section 5 and finally, conclusion and future research directions are offered in section 6.

2. Literature Review

According to Reinecke *et al.* (2007), supplier selection is the process by which the purchaser identifies, evaluates, and contracts with suppliers. The challenges mentioned above makes supplier selection a rich topic for operations and management science disciplines. Such kind of research is attracting a large volume of audience including management people having expertise in general as well as analytical decision making. This kind of research boosts the knowledge of decision makers in ever increasing domain of purchasing activities in different organizations.

Supplier selection has been viewed both by academics and practitioners as a multi-criteria decision process. For example, Weber *et al.* (1991) claim that 47 of the 76 articles reviewed addressed more than one criterion as part of supplier selection

decision making. Whereas, Dickson (1966), identified 23 different criteria for vendor selection including quality, delivery, performance history, warranties, price, technical capability and financial position. In addition, Siguaw, and Simpson (2004), identified a broad list of 84 supplier evaluation items in their study. The research investigated different criterion used in the evaluation of suppliers and their importance in the selection, retention process as well as their potential in adding value. This study identified the value adding characteristics of suppliers and also mentioned the importance of measuring such characteristics. These findings, however, should be extended to determine standardized criteria and methods for selecting and evaluating suppliers based on the value they add to the firm. Their proposed criterion were generalized and not targeting any particular type of industry. The authors also tried to highlight few of the extensions that can be carried in supplier selection based on the value addition phenomenon. In another study, Parthiban, *et al*. (2012), proposed multi-criteria decision making approach for supplier selection problems. The study dealt with the factors affecting the supplier selection and the interaction between each factor that have an effect on overall supplier selection.

Kahraman, *et al*. (2003), divided their supplier criteria under four main titles such as Supplier, Product Performance, Service Performance and Cost. All these criterion were further divided into sub criterion. They used Fuzzy-AHP approach to find out the relationship between them. However, the proposed study was based on interview of the purchasing managers of a white good manufacturer established in Turkey. They considered supplier selection problem as a multi-criteria decision making problem. Vonderembse and Tracey (1999), also considered supplier selection problem as a multi-criteria decision making problem and concluded that implementing supplier selection criteria and involving suppliers has a positive impact on performance. Jain *et al*. (2004), studied performance evaluation of suppliers using evolutionary fuzzy based approach. Later, Jain *et al*. (2009), provided a review of the main approaches to supplier-related issues especially supplier selection, supplier–buyer relationships, supplier–buyer flexibility in relationships in a dynamic supply chain. In another study by Rodriguez *et al*. (2013), they considered the supplier selection for customized equipment supplier's problem as a multi criteria decision making problem. The authors discussed about the possible and adequate multi criteria decision making tools. A combined fuzzy AHP and fuzzy TOPSIS approach was proposed in this work.

From the above literature review, clearly many authors have considered supplier selection problem as a multi-criteria decision making problem. Many published articles offer criteria used in supplier selection. For instance, Ha and Krishnan (2008), mentioned, Price, Quality and Delivery are the three most used attribute. Similarly, Koul and Verma (2012) also considered price, quality, cost and service as the major criteria in supplier selection. We will use in our study these most commonly used attributes in our ranking. Therefore, our major criteria for ranking of automotive supplier selection criteria will be 1) Price, 2) Quality, 3) Service and 4) Delivery.

There are many multi criteria decision making tools that were implemented in previous supplier selection criteria studies like DEA, ANP, AHP, and TOPSIS. For example, Memon *et al.* (2015) proposed a new tool for supplier selection and applied the combination of grey system theory and uncertainty theory which neither requires any probability distribution nor fuzzy membership function. The objective of this paper is to develop framework for reducing the purchasing risks associated with suppliers. In another study, Moghaddam (2015), developed a fuzzy multi-objective mathematical model to identify and rank the candidate suppliers and find the optimal number of new and refurbished parts and final products in a reverse logistics network configuration. On the other hand, Abdollahi *et al.* (2015), select an appropriate supplier portfolio based on two aforementioned concepts. Supplier selection problem is solved using a combination of multi-criteria decision making (MCDM) methods. Due to the interaction between the criteria, analytical network process (ANP) is applied for determining the weight of each criterion for each alternative (supplier), and then data envelopment analysis (DEA) is used to rank them.

Numerous studies in AHP for supplier selection have been reported in the literature. For example, Akarte *et al*. (2001) developed a web-based AHP system to evaluate the casting suppliers with respect to 18 criteria. Muralidharan *et al.* (2002) proposed a five-step AHP-based model to aid decision makers in rating and selecting suppliers with respect to nine evaluating criteria. Chan (2003) developed an interactive selection model with AHP to facilitate decision makers in selecting suppliers. Chan and Chan (2004) applied AHP to evaluate and select suppliers. Chan *et al*. (2007) developed an AHP-based decision making approach to solve the supplier selection problem. Potential suppliers were evaluated based on 14 criteria. Hou and Su (2007) developed an AHP-based decision support system for the supplier selection

problem in a mass customization environment. In another study, Deng *et al.* (2014), proposed D-AHP method for the supplier selection problem, which extends the classical analytic hierarchy process (AHP) method. Within the proposed method, D numbers extended fuzzy preference relation has been involved to represent the decision matrix of pairwise comparisons given by experts.

The AHP, developed at the Wharton School of Business by Saaty (1980), is one of the powerful and flexible weighted scoring decision making process to help people set priorities and make the best decision. AHP has been widely used to solve multi-criteria decision making in both academic research and in industrial practice. According to Vaidya and Kumar (2006), AHP has been implemented in almost all applications related to decision-making and is currently predominantly used in the theme of selection and evaluation especially in the area of engineering, personal and social categories. Ho (2008) and Dweiri and Al-Oqla (2006) mentioned that generally, implementing AHP is based on experience and knowledge of the experts or users to determine the factors affecting the decision process. Dweiri *et al.* (2015), proposes a ranking of forecasting methods for production planning in a supply chain. The proposed model is based on the analytical hierarchy process (AHP) since it has been proven useful in multi-criteria decision-making in many industrial and real life applications.

According to Hajeeh and Al-Othman (2005), AHP is an intuitive method for formulating and analyzing decisions whereas Cheng and Li (2001) cited that AHP approach is a subjective methodology. Adhikari *et al*. (2006), and Cheng *et al*. (2007) mentioned that AHP consists of three main principles, including hierarchy framework, priority analysis and consistency verification. Additionally, Hambali *et al.* (2008) defined the levels of AHP and said that formulating the decision problem in the form of the hierarchy framework is the first step of AHP, with the top level representing overall objectives or goal, the middle levels representing criteria and sub-criteria, and the decision alternatives at the lowest level.

In our paper we will use AHP as a multi criteria decision making tool because of its simplicity. AHP provides a realistic description of a problem by incorporating all aspects in the hierarchy. Moreover, AHP provides a useful mechanism for checking consistency of the evaluation measures and thus reducing bias in decision making. It is a robust technique that allows managers to determine preferences of

criteria for selection purposes, quantify those preferences, and then aggregate them across diverse criteria. It is a relatively easy approach to understand and apply.

Based on above successful applications of AHP for supplier selection problems in different fields, we decided to use AHP as a multi-criteria decision making tool for our study of ranking and sensitivity analysis of automotive supplier selection criteria.

2.1 Problem Definition and Research Gap

Supplier selection problems are considered as strategic problems in any organization. Automobile supply chains are quite complex as compared to other supply chains because of the presence of different types of suppliers in the chains. The suppliers differ in terms of the products they supply, size of the firm, capacity, quality, location etc. In order to remain competitive in the global market, companies need to structure themselves in their supply chains. The bonds/relationships that are developed in supply chains largely depend upon the supplier–buyer relationship, which is somehow an outcome of a supplier selection process.

This paper is considering well defined supplier selection criteria such as price, quality, delivery and services mentioned by Weber *et al.* (1996). He evaluated delivery and quality are extremely important supplier selection criteria followed by service and price which are considerably important. We added sub-criteria as per case company requirements to keep up the balance between literature and practice. Moreover, our identified criteria and sub-criteria are adding new dimensions in supplier evaluation criteria proposed by Wilson (1994). Similarly, De Boer *et al.* (2001) mentioned that supplier selection situations shows that not all methods are equally useful in every possible purchasing situation. This shows that we need specific methods, criteria and sub-criteria that suites our problem. Therefore, in order to accommodate his concern, we added few new sub-criteria in our proposed methodology. In a recent study, De Boer and Van der Wegen (2003) try to assess the apparent merit of using previously developed decision tools and approaches for supplier selection in practice by investigating the openness of decision makers to their use. Similarly, Aissaoui *et al.* (2007) mentioned that applying a range of techniques in the different phases of previously solved supplier selection cases can be utilized for the specific cases after some modifications. This shows that previously applied

criteria and sub-criteria for supplier selection can be modified and used in a specific environment like we did in our proposed methodology.

Our case company has been struggling and facing problems such as rejection rate during incoming inspection. Moreover, they did not have a systematic and appropriate approach for selecting suppliers. It is not uncommon for automotive industry in many developing countries not having decision support system for supplier selection which can address the lingering problem of creating appropriate supplier base. Consequently, the motivation behind this study was to propose a scalable and generalizable AHP based effective and efficient decision support system to resolve this problem for the case company.

The AHP has found extensive application in decision-making problems, involving multiple criteria in multi-level systems. One of the strongest features of the AHP is that it generates numerical priorities from the subjective knowledge expressed in the paired comparison matrices. The method is useful in evaluating suppliers' weights in terms of various factors. The present study is a step in developing a supplier selection technique using AHP and is applied to automotive industry in Pakistan.

The highlighted literature in the previous section is devoid of methodology that explains the different short listed criteria for supplier selection in automobile industry. Furthermore the authors find it important to come up with a simple decision support methodology for managers in automotive industry in Pakistan used as an example so that they can select the best suppliers from a list of them.

2.2 Contribution of the Study

Our contribution in supplier selection literature can be summarized as follows:

i) This paper points out the importance of supplier selection process specifically in the field of automotive parts manufacturer in a developing country.

ii) This paper provides useful insights of supplier selection and application of scalable and generalizable AHP based decision support system in a dynamic and growing automotive industry in a developing country.

iii) Automotive industries are known in facing heterogeneous supply environments and proposed approach will cater to this issue.

iv) Proposed methodology has been successfully implemented in a case company and company reduced incoming rejection rate by 8%.

3. Methodology

In order to rank automotive suppliers in Pakistan using AHP, a decision support system framework is developed as shown in Figure 1.

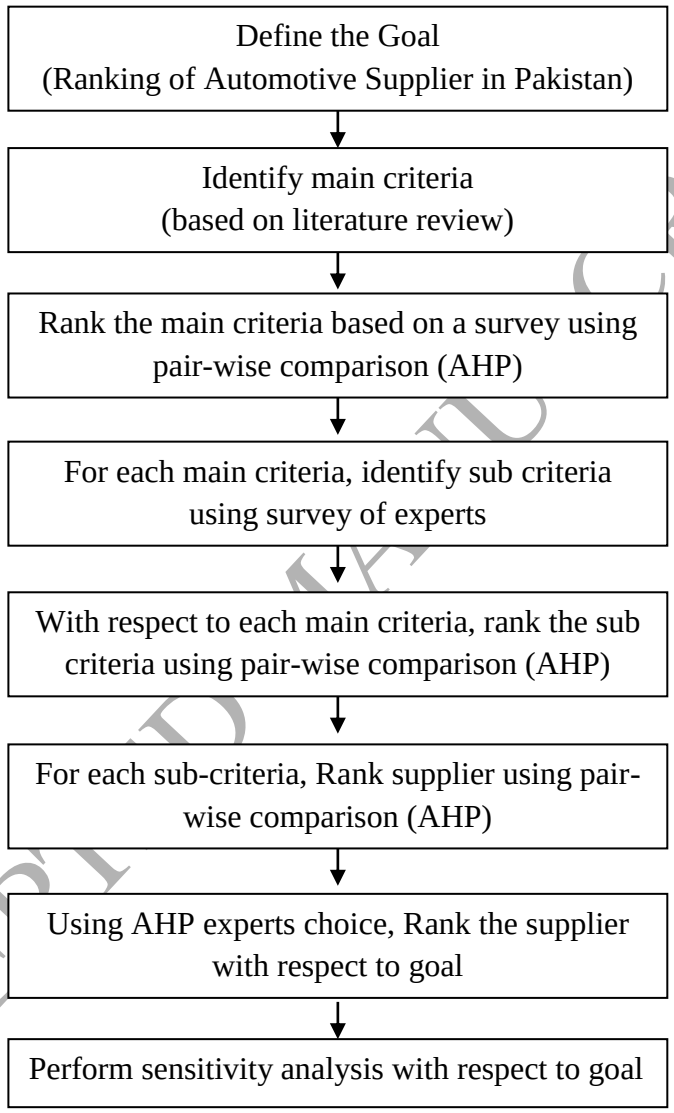

Figure 1. AHP based Decision Support Framework

Following the decision support framework shown in Figure 1, the goal of ranking the suppliers is determined. We identified Price, Quality, Delivery and service as main criteria based on literature review. The main criteria's are ranked based on experts' opinions using surveys. Experts were asked to perform pair wise comparison of the criteria based on the importance scale shown in Table 1.

Table 1. Importance Description

Score	Importance Description
1	" i" is equal important to " j"
3	" i" is weakly more important to " j"
5	" i" is strongly important to " j"
7	" i" is very strongly important to " j"
9	" i" is absolute morel importance to " j"
Note: 2, 4, 6 and 8 are intermediate values.	

Out of 72 surveys mailed, 23 were completed and returned. Nineteen companies returned the survey saying that due to large number of such queries they were unable to respond. Thirteen companies did not respond at all and seventeen companies said that they were unable to reply because their company was not suitable for such kind of survey. The response rate was only 32%. Since the size of population of interest is small, then the sample size can be relatively small. In this study, the selection of sample size was based on the most widely used rule-of-thumb, described by Olejnik (1984) ''Use as many samples as you can get and you can afford''. Therefore, authors believes that the 32% of response rate is adequate to assist us in developing our framework.

The survey was mainly distributed to the local companies which are located in major cities of Pakistan such as Karachi, Lahore, Rawalpindi, and Islamabad. Most of the surveys were sent to the experts via email. Few of them were sent via local post. We selected companies which have core business in automotive parts manufacturing. The duration of surveys which includes time from sending the surveys and receiving responses were between February and November, 2014. Table 2 shows the demographic summary of surveyed companies and appendix 1 shows the actual survey that was sent to surveyed companies.

Table 2. Demographics Details of Surveyed Companies

Examples of Product Type	Examples of Quality Certification	No. of Different Parts Manufactured	Examples of Expert Titles	Skills and Responsibilities
Automotive Parts Such as Wheel Caps, Internal Garnishes, Outside Door Handles, Bumpers, Door Trims, Roof Headliners, Steering Wheels, Panel Instrument Cluster & Switch Set Power Window, Seats	• QS-9000 • ISO-14001 • OSHAS 18001 • TS-16949	Approximately 50-75 Different Plastic Parts Manufacturer	• Manager Technical • Operations Managers • Assistant Manager Quality Assurance • Supply Chain Executive • Assistant Manager Procurement • Quality Engineer • Procurement Executive • Purchasing Manager	• Managing all technical evaluation of supplied parts. • Overall responsible of operations. • Making quality standards of supplied parts from suppliers. • Selecting suppliers based on identified criteria.

Then for each main criterion, sub criterions are identified in the second level of hierarchy based on experts' opinions as well as the 3 suppliers shown in Figure 2.

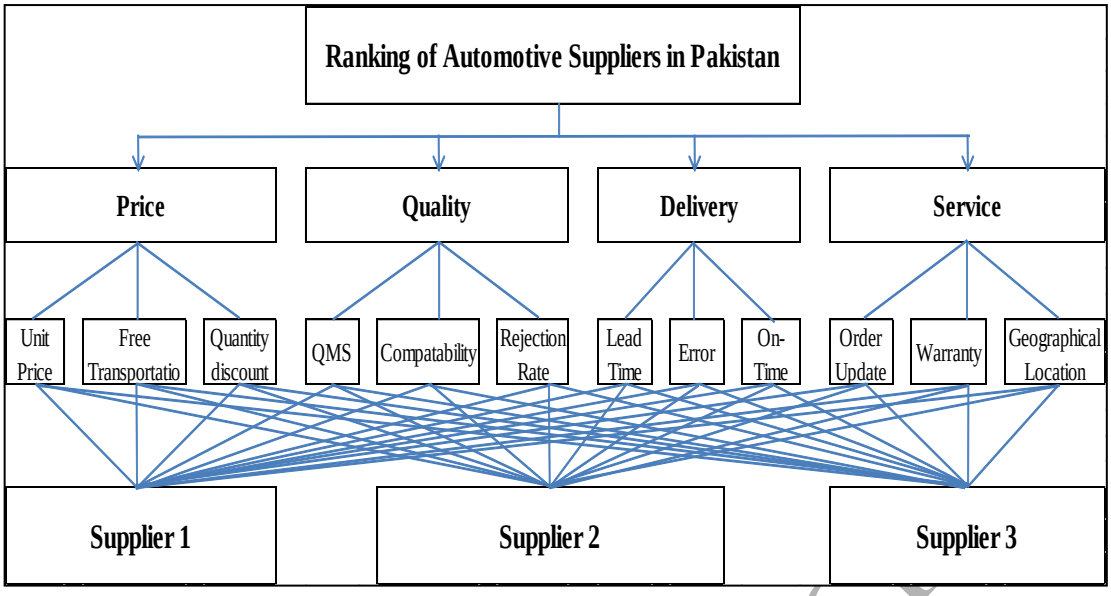

Figure 2. AHP Hierarchy

In this study, we consider three main suppliers for ranking. Selection of main three suppliers were based on company recommendation and table 3 will provide information about selected suppliers. Names of these suppliers are withheld due to confidentiality.

Suppliers can be heterogeneous in many ways such as one supplier can supply different kinds of products, many supplier can provide one product type, or many suppliers can provide many kinds of products. Consideration of heterogeneity in supplier selection is important for effective selection of supplier. Many authors consider heterogeneity in their supplier selection problem such as Saen, (2009) used estimations in the form of intervals in their considered supplier selection problem. These intervals are based on expert opinions. Similarly, Kumar, et al. (2014) proposed Green DEA approach for green supplier selection and incorporates heterogeneous suppliers and also takes into account regional emission compliance standards and laws.

This paper proposed an AHP based supplier selection model in an automobile industry in Pakistan. Case company in Pakistan has heterogeneous suppliers in terms of their product type, number of products they manufactured, number of products they supplied, and size of facilities. Table 3 below shows details of heterogeneous suppliers that we considered in our case study.

Table 3. Selected Suppliers Information

S. No.	Supplier Name	Location	Product Supplied	Established Year	Company Size
1	Supplier 1	N.W.I. Zone Port Qasim, Karachi Pakistan	Assembly Parts for Wheel Caps, Internal Garnishes, Door Trims, Roof Headliners, Steering Wheels, Panel Instrument Cluster & Switch Set Power Window, Seats.	1988	Large
2	Supplier 2	Downstream Industrial Estate, Karachi Pakistan		1990	Medium
3	Supplier 3	Korangi Industrial Area, Karachi Pakistan		1996	Medium

The experts' opinions of pair wise comparison using Table 1 is summarized and shown in Table 4.

Table 4. Experts Opinions for Pair-Wise Comparison

	Delivery	**Price**	**Quality**	**Service**
Delivery	-	1/3	1/2	2.0
Price	3	-	2.0	4.0
Quality	2	1/2	-	3.0
Service	1/2	1/4	1/3	-

Table 2 is represented in matrix **A** and will be used to illustrate how AHP works.

$$\mathbf{A} = \begin{pmatrix} 1 & \frac{1}{3} & \frac{1}{2} & 2 \\ 3 & 1 & 2 & 4 \\ 2 & \frac{1}{2} & 1 & 3 \\ \frac{1}{2} & \frac{1}{4} & \frac{1}{3} & 1 \end{pmatrix}$$

The sum of the columns A = (6.5 2.08 3.83 10)

To check for the consistency of the experts' opinion, a normalized matrix **N** is found by dividing each element of the matrix **A** by the sum of the respected column.

$$\mathbf{N} = \begin{pmatrix} 0.15 & 0.16 & 0.13 & 0.20 \\ 0.46 & 0.48 & 0.52 & 0.40 \\ 0.31 & 0.24 & 0.26 & 0.30 \\ 0.08 & 0.12 & 0.01 & 0.10 \end{pmatrix}$$

To find the weight of each criteria a matrix **W** is found by calculating the average for each row of the matrix "**N**".

$$\mathbf{W} = \begin{pmatrix} w_1 = \frac{0.15+0.16+0.13+0.20}{4} = 0.16 \\ w_2 = \frac{0.46+0.48+0.52+0.40}{4} = 0.47 \\ w_3 = \frac{0.31+0.24+0.0.26+0.30}{4} = 0.28 \\ w_4 = \frac{0.08+0.12+0.01+0.10}{4} = 0.10 \end{pmatrix}$$

Notice that $\sum W_i = 1.00$.

To check for the consistency of the decision maker judgment, the Eigen value(λ_{max}) is found by

$$\lambda_{max} = \sum AW$$

Where

$$\mathbf{AW} = \begin{pmatrix} 1 & \frac{1}{3} & \frac{1}{2} & 2 \\ 3 & 1 & 2 & 4 \\ 2 & \frac{1}{2} & 1 & 3 \\ \frac{1}{2} & \frac{1}{4} & \frac{1}{3} & 1 \end{pmatrix} \text{ x } \begin{pmatrix} 0.16 \\ 0.47 \\ 0.28 \\ 0.10 \end{pmatrix} = \begin{pmatrix} 0.65 \\ 1.89 \\ 1.12 \\ 0.38 \end{pmatrix}$$

$\lambda_{max} = \sum AW = (0.65+1.89+1.12+0.38) = 4.04$

The judgment is considered consistent when λ_{max} is close to the criteria (n).

$$\text{Consistency Index (CI)} = \frac{\lambda max - n}{n-1}$$

$$CI = \frac{4.04-4}{4-1} = 0.0133$$

$$\text{Random Inconsistency (RI)} = \frac{1.98\ (n-2)}{n}$$

$$RI = \frac{1.98\ (4-2)}{4} = 0.99$$

$$\text{Consistency Ratio (CR)} = \frac{CI}{RI}$$

$$CR = \frac{0.0133}{0.99} = 0.01$$

Since CR ≤ 0.1, the consistency ratio of A is acceptable.

The above mentioned results are based on the qualitative judgment of automotive industry experts in Pakistan. Their judgments are also performed on the Expert Choice™ software as shown in Figure 3.

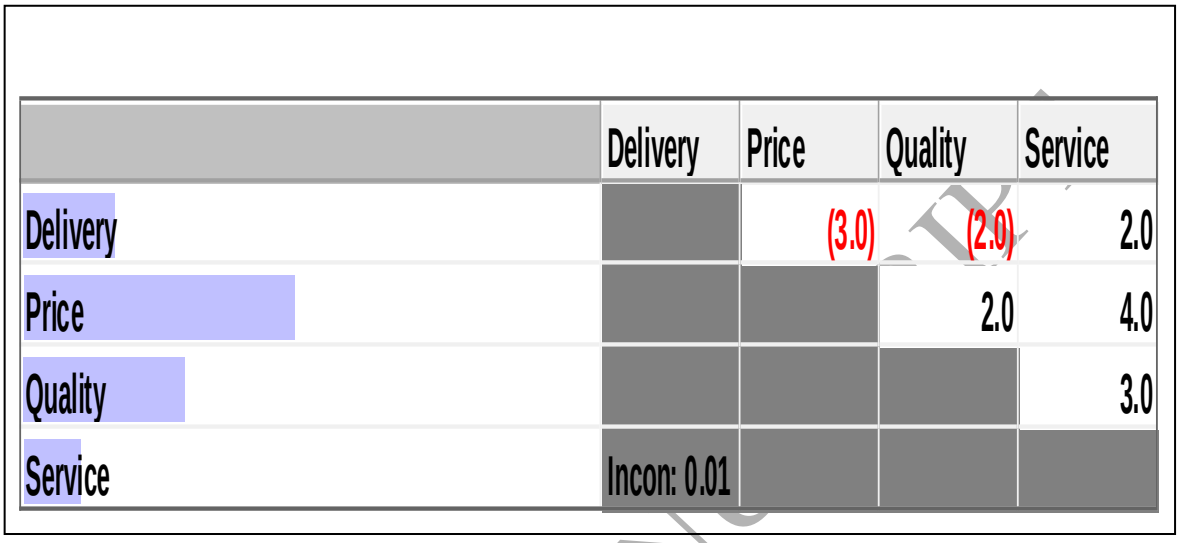

Figure 3. Automotive Industry Experts' Judgements Results by Expert Choice™ Software

Figure 3 shows that the judgment is consistent since the inconsistency ratio is 0.01

The pair wise comparison is also used to rank the sets of sub criteria with respect to their associated main criterion. The results are shown in Figures 4, 5, 6 and 7.

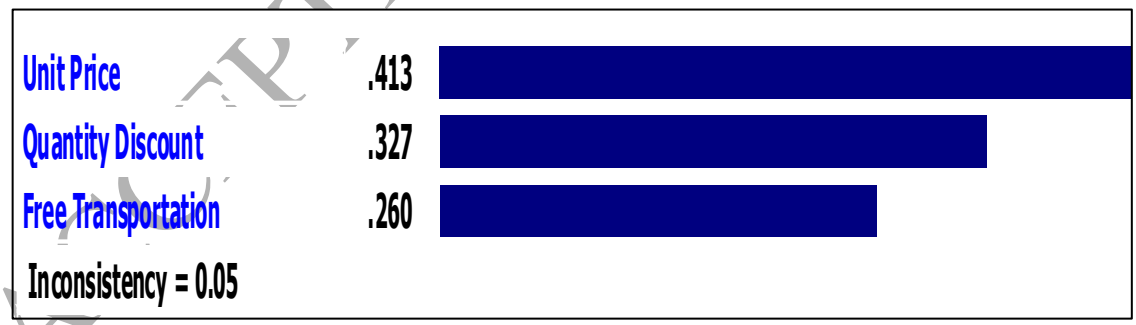

Figure 4. Ranking of Sub Criteria With Respect to Main Criteria "Price"

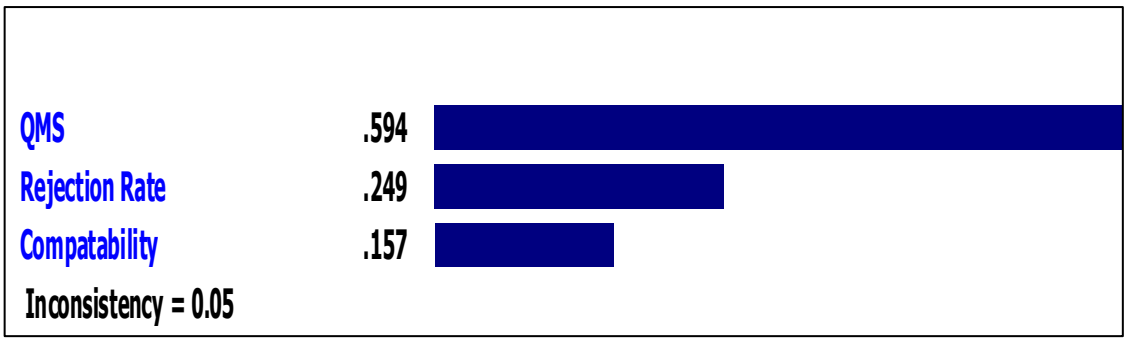

Figure 5. Ranking of Sub Criteria With Respect to Main Criteria "Quality"

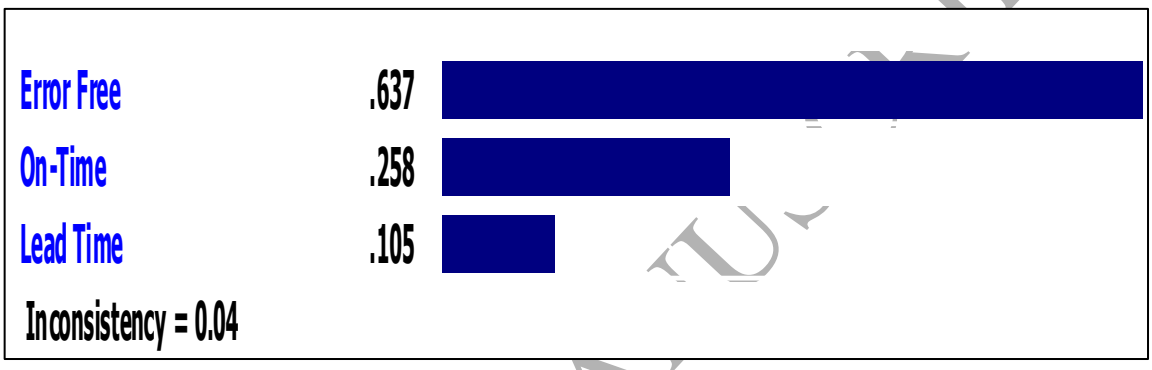

Figure 6. Ranking of Sub Criteria With Respect to Main Criteria "Delivery"

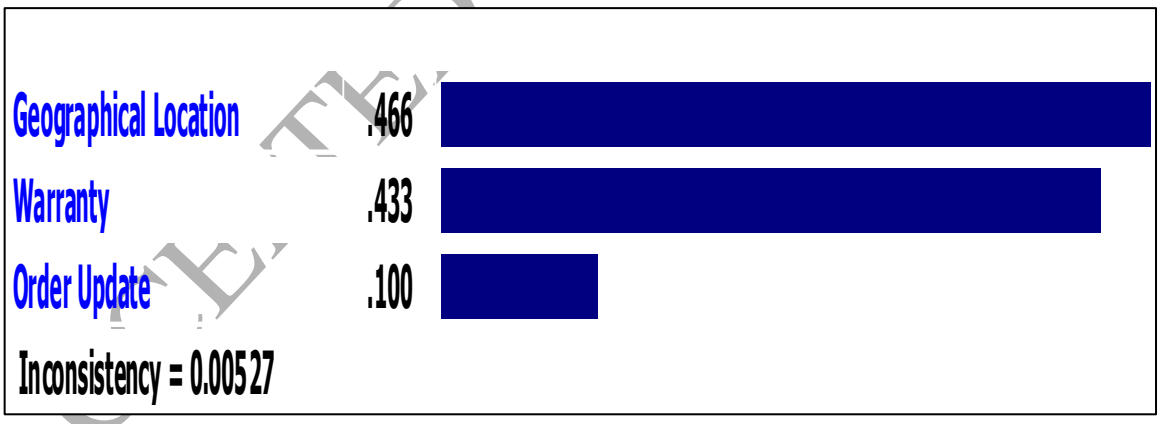

Figure 7. Ranking of Sub Criteria With Respect to Main Criteria "Service"

Also the three suppliers are ranked based on the sub criterion using the same methodology. The results of using Expert Choice™ are shown in Figure 8.

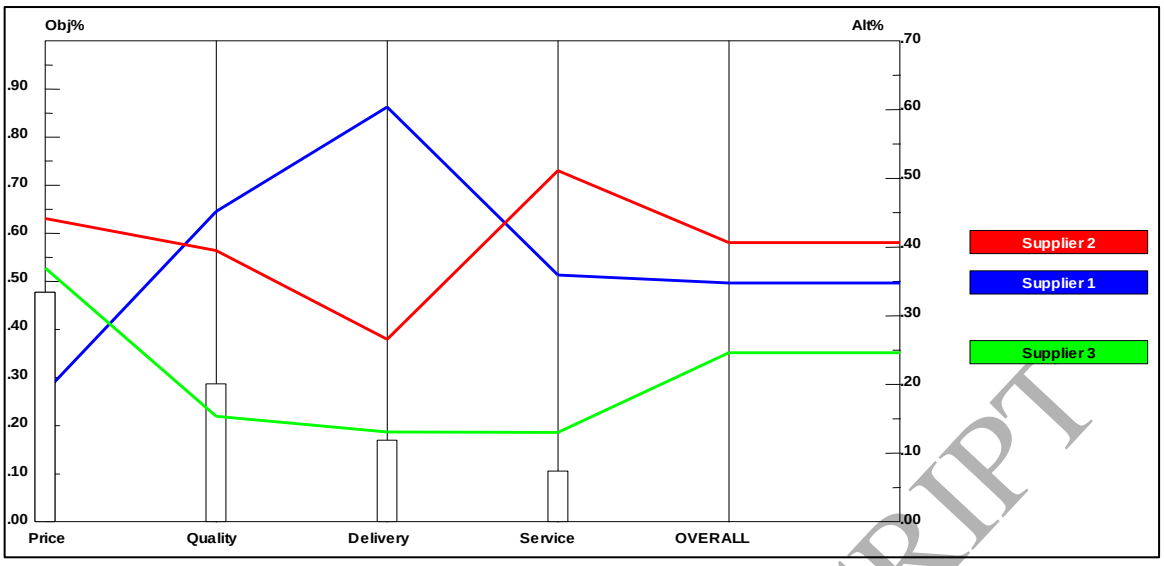

Figure 8. Ranking of Suppliers Based on Sub Criterion

3.1 Sensitivity Analysis

The sensitivity analysis of the suppliers ranking is performed using Expert Choice™ software. The sensitivity analysis is useful to understand the effect of changing weights of the main criteria on the ranking of suppliers. The analysis is performed by changing the weight of each main criterion as shown next.

Sensitivity Analysis with respect to Price: The ranking of supplier will change from Supplier (2, 1, 3) to Supplier (2, 3, 1) when Price is 68%, Quality is 17%,-Delivery is 9% and Service 6%. The result is mentioned in Figure 9. If we decrease the price percentage from its original weight to 46.6%, ranking of supplier will change from Supplier (2, 1, 3) to Supplier (1, 2, 3) when Price is 31%, Quality is 37%, Delivery is 21% and Service is 11%. The result is shown in Figure 10.

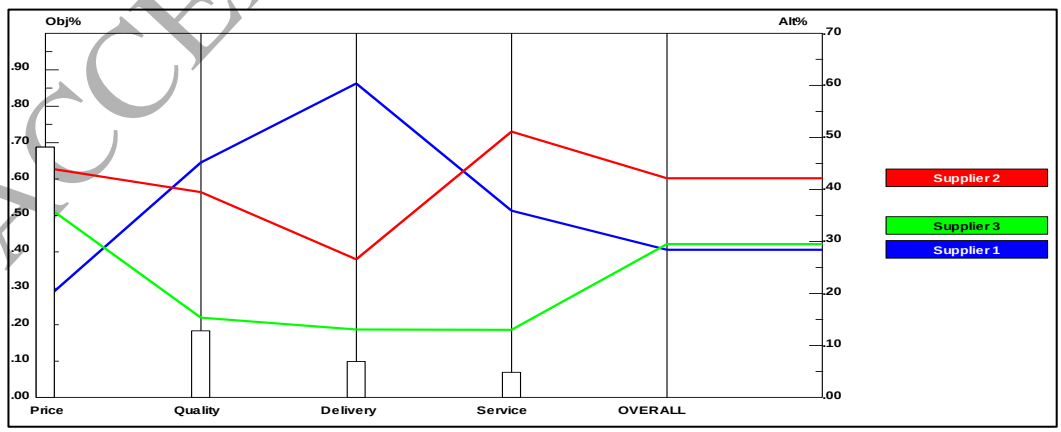

Figure 9. Sensitivity Analysis With Respect to Price (Upward Change)

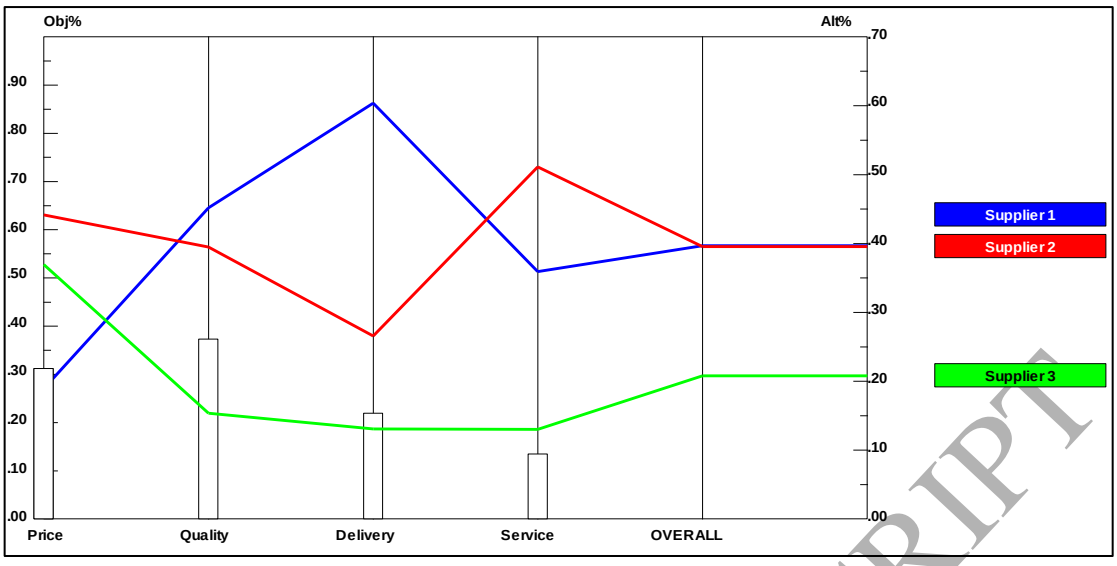

Figure 10. Sensitivity Analysis With Respect to Price (Downward Change)

Sensitivity Analysis with respect to Quality: The ranking of supplier will change from Supplier 2, Supplier 1 & Supplier 3 to Supplier 1, Supplier 2 and Supplier 3 when Price is 23%, Quality is 66%, Delivery is 6% and Service is 5%. The result is mentioned in Figure 11. The ranking of supplier is robust and will not change if we decrease the quality percentage from its original weight 27.8%.

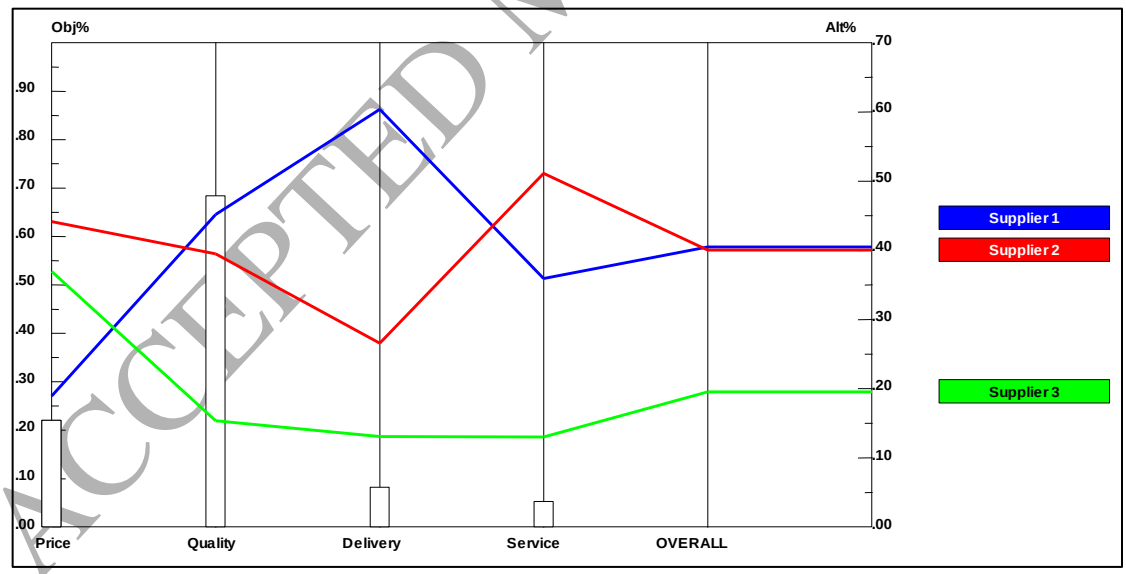

Figure 11. Sensitivity Analysis With Respect to Quality (Upward Change)

Sensitivity Analysis with respect to Delivery: Our proposed ranking of supplier will change from Supplier 2, Supplier 1 & Supplier 3 to Supplier 1, Supplier 2 and Supplier 3 when Price is 40%, Quality is 24%, and Delivery is 30% and Service is

8%. The result is mentioned in Figure 12. The ranking of supplier is robust and will not change if we decrease the Delivery percentage from its original weight of 16%.

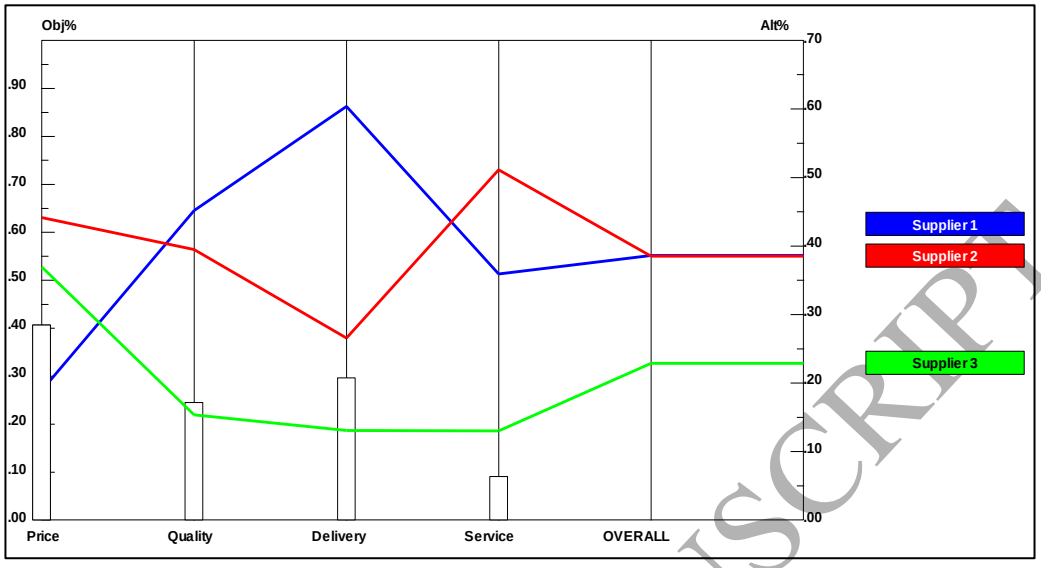

Figure 12. Sensitivity Analysis With Respect to Delivery (Upward Change)

Sensitivity Analysis with respect to Service: Our top rank supplier and ranking will not change (robust) regardless of any value of Service.

4. Conclusion and Future Research Directions

Selecting an appropriate supplier plays a vital role in the supply chain performance of the organization in order to meet customer demand in a timely and cost effective manner in order to achieve their satisfaction. This paper proposed a model for ranking the suppliers for the automotive industry in Pakistan used as an example. Due to the complexity of the problem, we used the multi criteria decision making tool (AHP). The problem is divided into two hierarchies (main criteria and sub criteria). The main criteria (Price, Quality, Delivery and Service) are identified based on literature review. These criterions are ranked based on the experts' opinions using AHP pair wise comparison approach. The results of the ranking of the main criteria are Price (47%), Quality (28%), Delivery (16%) and Service (10%) with inconsistency of 0.01. Sets of sub criterion are identified and ranked with respect to their associated main criteria using the same process. Three suppliers are selected and ranked in this process. Finally, sensitivity analysis is performed to study the effect of changing the weights of the main criteria on the ranking of suppliers. The benefits of

this approach are that it divides the complex problem into simpler hierarchy as well as low inconsistency of the decision makers' judgments. The use of sensitivity analysis identified the range of change of the main criterion weights while the ranking of supplier stay robust.

The case studied in this paper has significant managerial implications. The AHP methodology adopted in this study provides managers in automotive industry with the insights of the various factors that need to be considered while selecting suppliers for their organization. The selected approach also aids them in prioritizing the criterion. Managers can utilize the hierarchical structure of adopted supplier selection methodology suggested in this study to rank the suppliers on the basis of various factors/criterion. The sensitivity analysis performed in this study also analyzes the effect of changing the weights of the main criteria on the ranking of suppliers which will help managers in decision making. This approach will also help managers in dividing the complex problem into simpler hierarchy.

Proposed methodology has been successfully implemented in the case company and after few months of implementation, company noted reduction in incoming rejection by 8%. Management of case company is willing to utilize supplier ranking that was identified in this paper and allocate orders according to their rank.

Authors are unaware of research in the existing literature on supplier selection and focus on problems related to suppliers in a developing country. Notably automotive industry in Pakistan is currently booming and shows promising growth during the last five years. This study helped a case company in reducing their rejection rate at incoming inspection. Management of this company is very much convinced about our proposed approach which is easy to implement and at the same time they found it effective. They confirmed intricacy and efficiency of our proposed approach.

The factors affecting supplier selection could be qualitative or quantitative. There are many qualitative concerns when assessing the factors critical to supplier selection. Some of the factors included in our study were difficult to quantify for example service, quality. Different hybrid techniques such as fuzzy AHP, fuzzy TOPSIS, ANP can be used to address this gap. Also in future, different supply chain sectors can be considered and a thorough comparison can be made highlighting the challenges in supplier selection for these different sectors. Also, order splitting strategies can be linked with supplier selection in the future.

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Appendix 1

Survey

We are conducting research in which we will develop a decision support system which helps in ranking of automotive suppliers based on certain criteria. We will appreciate hearing from you about the importance of each criteria suggested based on your expertise. This will help us in ranking suppliers for automotive industry. The survey will take around 5 to 6 minutes, and your responses are completely anonymous. We really appreciate your time.

Please answer the following questions by choosing a number to rate the importance of a criteria on the scale provided.

In this section, four major criteria will be rated:

- **Price:** Purchasing price of product.

- **Quality:** Quality of the delivered product.
- **Delivery:** On time delivery rate.
- **Service:** How well suppliers provides its service.

Note:

- ✓ By choosing 1 you declare an equal rating between the criteria.
- ✓ The lowest rating you can choose is 2 which indicates a Low importance of the criteria on the side you chose the number for.
- ✓ The highest rating you can choose is 9 which indicates a High importance of the criteria on the side you chose the number for.

Please proceed with choosing the ratings as follows:

Price	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Quality
Price	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Delivery
Price	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Service
Quality	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Delivery
Quality	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Service
Delivery	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Service

In this section, the following sub-criteria will be rated with respect to *Price*

- **Unit Price**: The unit price of the product.
- **Free Transportation**: Supplier is delivering product free of charge.
- **Quantity Discount**: Supplier is offering certain percentage discount if quantity increases.

Note:

- ✓ By choosing 1 you declare an equal rating between the criteria.
- ✓ The lowest rating you can choose is 2 which indicates a Low importance of the criteria on the side you chose the number for.
- ✓ The highest rating you can choose is 9 which indicates a High importance of the criteria on the side you chose the number for.

Please proceed with choosing the ratings as follows:

Unit Price	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Free Transportation
Unit Price	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Quantity discount
Free Transportation	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Quantity Discount

In this section, the following sub-criteria will be rated with respect to *Quality*

- **Quality Management System**: Does the supplier has QMS.
- **Rejection Rate** Rejection rate of product delivered by a particular supplier.
- **Compatibility**: Is the supplier products are compatible.

Note:

- ✓ By choosing 1 you declare an equal rating between the criteria.
- ✓ The lowest rating you can choose is 2 which indicates a Low importance of the criteria on the side you chose the number for.
- ✓ The highest rating you can choose is 9 which indicates a High importance of the criteria on the side you chose the number for.

Please proceed with choosing the ratings as follows:

QMS	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Rejection Rate
QMS	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Compatibility
Rejection Rate	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Compatibility

In this section, the following sub-criteria will be rated with respect to *Delivery*

- **Lead Time**: How much time a supplier is taking to deliver a product.
- **Error**: How many times suppliers deliver wrong product in terms of quantity or specifications.
- **On time Delivery:** How many times supplier deliver product on premised date

Note:

- ✓ By choosing 1 you declare an equal rating between the criteria.
- ✓ The lowest rating you can choose is 2 which indicates a Low importance of the criteria on the side you chose the number for.
- ✓ The highest rating you can choose is 9 which indicates a High importance of the criteria on the side you chose the number for.

Please proceed with choosing the ratings as follows:

Lead Time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Error
Lead Time	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	On Time Delivery
Error	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	On Time Delivery

In this section, the following sub-criteria will be rated with respect to *Service*:

- **Order Update**: How frequently supplier is updating about order status.
- **Warranty**: How long they provide warranty of delivered product.
- **Geographical Location**: How close the location of supplier facilities to the company.

Note:

- ✓ By choosing 1 you declare an equal rating between the criteria.
- ✓ The lowest rating you can choose is 2 which indicates a Low importance of the criteria on the side you chose the number for.
- ✓ The highest rating you can choose is 9 which indicates a High importance of the criteria on the side you chose the number for.

Please proceed with choosing the ratings as follows:

Order Update	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Warranty
Order Update	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Geographical Location
Warranty	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Geographical Location

Thank you very much for participating in our survey!