

ORIGINAL ARTICLE

Supply Chain Management of Outsourcing Module Components Decision-Making using Analytical Hierarchy Process and Visual Basic Application in Automotive Body-in-White Welding Assembly Line

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ABSTRACT – Supply Chain Management (SCM) has gained the attention of business organizations as it affects corporate efficiency and competitive advantage. Component outsourcing is an important element of SCM practices and is considered to be a multi-criteria decision-making problem (MCDM) in vendor selection processes. However, decision-making on the selection of vendors is crucial, as the outsourcing program is influenced by multiple technical and commercial criteria of vendors. Developing an Excel-based Analytic Hierarchy Process (AHP) model for vendor selection therefore helps to simplify selection processes. In this paper, a Visual Basic Application (VBA) Excel-based AHP model was developed, which multiple criteria, sub-criteria and vendors and simultaneously compared with multiple main criteria, sub-criteria and alternatives for vendor selection. The model was validated with a case study of selecting a vendor for module components of body-in-white (BIW) in automotive industry as industrial application. As a result, vendor A is the best vendor since it has the highest overall score of 0.35206. Whereas vendor B is 0.239, vendor C is 0.126, vendor D is 0.146 and vendor E 0.135. In addition, the model is capable of resolving other MCDM problems. This paper provides resources such as AHP methodology, validating method and VBA code programming to readers in developing their own VBA Excel-based model.

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INTRODUCTION

The selection process of suppliers involves several strategic variables with the intention of maximizing the total value to the buyer and lowering the risk [1]. Conventionally, vendors or suppliers have been selected solely based on price for several years, and it has been found that price as a single criterion is not enough [2]. Therefore, Ho et al. mentioned that vendor selection involves qualitative and quantitative factors rather than price alone [3]. For instance, supplier's past performance, net price, geographical location, communication systems, service, delivery and quality are the main supplier selection criteria in evaluating a supplier's performance, as stated by authors in [4-7]. Recently, in SCM decision making, approaches for evaluating green supplier performance and environmental issues are major concerns [8, 9].

Vendor selection is normally done by creating a list of evaluation criteria before comparing the potential vendors' proposal. Chai et al. stated that the real world's diversity and complexity are the reason of widely accepted effective methodological framework for vendor selection not settled [10]. Hence, data envelopment analysis (DEA), analytic network process (ANP), analytic hierarchy process (AHP), mathematical programming (MP), VIKOR method and goal Programming (GP) are several proposed mathematical tools that help decision makers evaluation for vendor selection [11, 12]. Furthermore, integrated or mixed the above-mentioned models are proposed by some researchers.

Despite all the various approaches, the AHP model is the most popular approach in vendor selection. This is supported by Chai et al., who have conducted a systematic literature review on 123 articles regarding the application of decision-making models in vendor selection which were published from 2008 to 2012 as shown in Figure 1 [10, 13]. Hence, there are various decision-making software being developed to help individuals and organizations in making decision through ranking, prioritizing or choosing from a number of options.

In modern-day, the utilization of software is broadly acknowledged by industries since it helps to enhance productivity without losing its accuracy and consistency in work. Expert Choice, Logical Decision, Decision Lens, Super Decisions, Analytica and D-Sight are some notable examples of decision-making software in the market. Most of the decision-making software mentioned above employs AHP as their MCDM method. This is supported by the fact that AHP is able to reduce complex decision-making problems to a series of one-on-one comparisons and then produce results.

Researchers have successfully applied AHP to vendor rating and hence concluded its usefulness, practicality and systematically [14]. Therefore, the AHP model of decision-making software is used in selecting vendors. The reasons for choosing AHP as the MCDM method for selecting vendor are that AHP provides a systematic way of handling with

MCDM problem, and it is extensively studied and applied in the industries. Moreover, AHP provides feedback on the given judgment by using consistency test, hence, making sure that the judgment is consistent throughout the vendor selecting process. AHP works by translating empirical comparisons into numerical values that allow decision-makers to turn their assessment into a judgment [15].

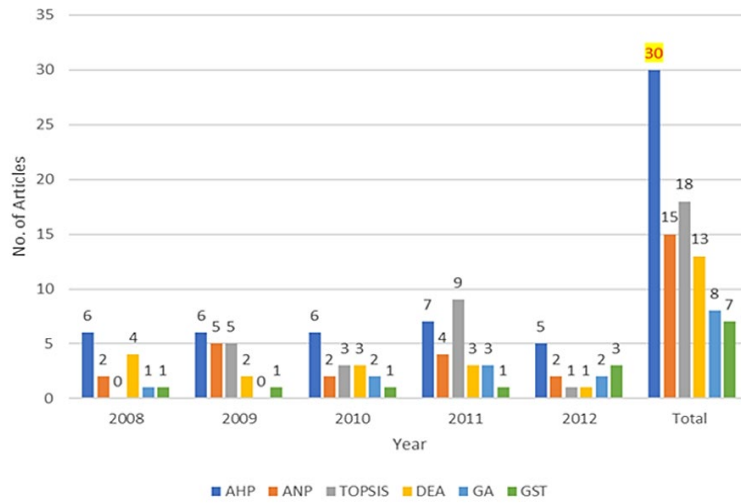


Figure 1. Chronological distribution of some major DM techniques, adapted from [13].

The existing field of work established criteria, sub-criteria and alternatives to solve the selection problem. The author proposed a study to accelerate the selection process through an algorithm. The objective of this paper is to develop an AHP model of module components outsourcing in selecting a vendor. Therefore, the vendor selection criteria have to be identified by reviewing the literature while constructing a decision hierarchy. Next, the VBA code scripting incorporated with Microsoft Excel is developed after comprehending the methodology of AHP. Finally, the developed model is validated using the industrial case study.

COMPONENT OUTSOURCING SELECTION MODEL – A REVIEW

The components outsourcing selection model is a multi-criteria decision making (MCDM) process. Authors have proposed various MCDM models for tackling vendor selection in various literature. The decision-making model can be categorized into individual model and integrated (mixed) model, as in Figure 2. The individual model can also be divided into MCDM models, mathematical programming (MP) models, and artificial intelligence (AI) models. In the era of Internet of Things and Big Data (IoTBD), the selection process would face several challenges and prompt decision on the large scale of criteria from the cloud [16]. Chai et al. define MCDM as a methodological framework for evaluating the decision problem from multiple perspectives, which is known as criteria and then giving an insightful suggestion to decide from a fixed list of alternatives [10, 13].

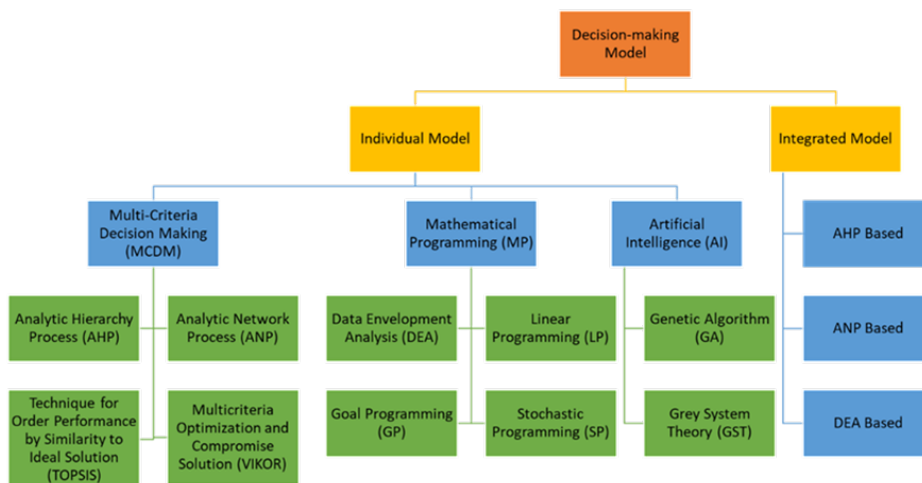


Figure 2. Types of decision-making model for vendor selection.

There are several types of MCDM worth mentioning, such as AHP, Analytic network process (ANP), Technique for order performance by similarity to ideal solution (TOPSIS), and Multi-criteria optimization and compromise solution (VIKOR). ANP is able to show the relationship between alternatives and criteria through network structure. In fact, ANP is a progression from AHP [17]. TOPSIS identifies the optimal solution which is the closest to the positive ideal solution

but the furthest from the negative ideal solution. VIKOR permits simultaneous consideration of closeness to perfect and imperfect alternatives through a simple computation procedure.

Adler et al. stated data envelopment analysis (DEA) model evaluates the relative efficiency of comparable entities based on several inputs and outputs [18]. Linear programming (LP) uses a mathematical model which relates to several requirements, known as linear relationships, to achieve the best results. Stochastic programming (SP) is used to model optimization problems by exploiting the probability distributions to deal with uncertainty. Genetic algorithm (GA) and grey system theory (GST) are examples of major AI models. GA uses the concept of a biological process of evolution to obtain approximate solutions. The solution is not guaranteed to be strictly optimal since it is a heuristic method [13]. GST is a mathematical method that is targeted to cope with the uncertainty of a system because of incomplete information in the form of interval values [19].

There are several types of integrated approaches worth mentioning, such as the integrated AHP and DEA model, integrated AHP and GP model, integrated AHP and grey relational analysis (GRA) model and integrated fuzzy and AHP model. Ramanathan proposed that the integration of AHP and DEA models is done by using weights obtained from AHP model as the input for DEA model to evaluate the supplier’s performance [20]. Regarding the integrated AHP and GP model, Çebi and Bayraktar suggested that criteria’s weights from AHP were to be used as the input for GP model to determine the best raw material supplier list and the number of raw materials needed [21]. Regarding the integrated AHP and GRA model, Yang and Chen determined the weights of qualitative criteria through AHP model before using them as GRA model’s coefficients [7]. The supplier with the highest grey relational grade value is selected. Grey relational grade values are produced by GRA model which combines both quantitative and qualitative data. Regarding the integrated fuzzy and AHP model, Chan and Kumar used the fuzzy synthetic extent analysis method and triangular fuzzy numbers to represent Saaty’s scale of comparison judgment in the weights of criteria [22].

AHP is a general measurement theory which relies on the judgements and values of individuals and groups. Pairwise comparison judgements are done along with a hierarchic structure in order to obtain weights or priorities [23-24]. It has been broadly practised in solving multi-criteria decision-making problems in various fields [25-29]. Figure 3 shows the hierarchy representation in AHP helps a decision maker to decompose the problem into its underlying component systematically and structurally [30]. Moreover, AHP is designed to deal with both tangible and intangible criteria. In addition, the consistency test in AHP is used to ensure that the judgment made is consistent and AHP has the flexibility to be integrated with other models [31].

METHODOLOGY

The process flow of applying AHP methodology in vendor selection is shown in Figure 4. The flowchart describes the steps taken in the decision-making process of vendor selection. The AHP methodology was adopted from Saaty, but the study was categorized into four composition stages to accelerate the selection process by using an algorithm. In this phase, a Visual Basic Algorithm (VBA) code programming establish to automate the process of computation. It is mainly as a well-defined a step by step instruction prepared in sequence in order to solve a problem. The manual process of computation is a very repetitive and tedious task. The automated process of computation is very essential for industrial practical application. In this study, the algorithm was developed using a flowchart. A VBA code programming is then developed based on the instruction or sequence order in the algorithm.

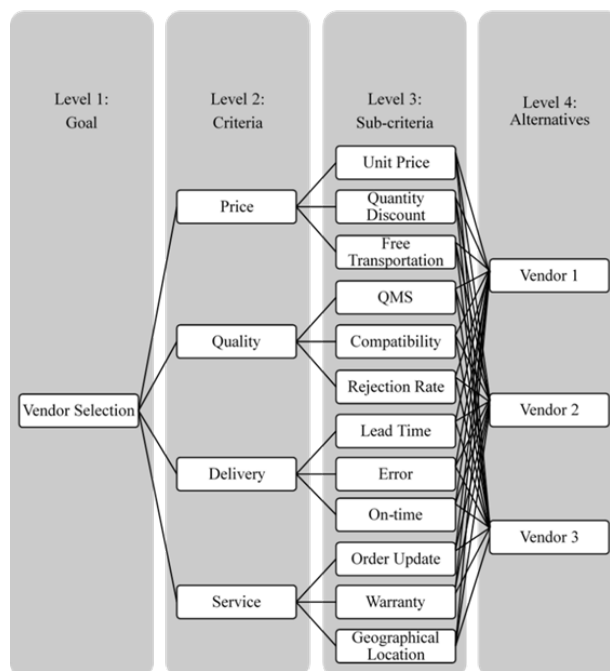


Figure 3. Example of decision hierarchy for vendor selection.

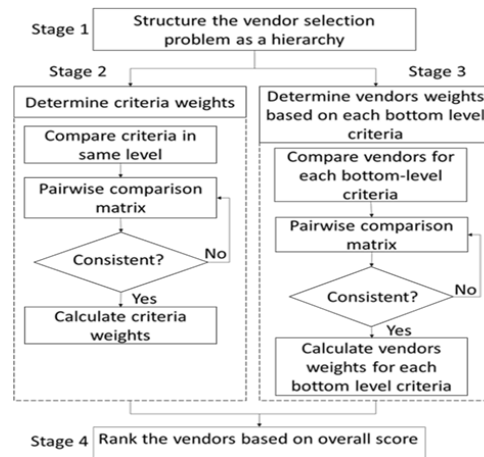


Figure 4. Process flow of vendor selection using AHP methodology.

i. Stage 1 is structuring the vendor selection problem into a hierarchy

Developing an AHP model for vendor selection started with establishing the criteria of vendor selection. It is an efficient approach in simplifying its complexity and identifying the essential criteria and sub-criteria of vendor selection based on the perspective of a decision maker. The criteria selection varies with the type of industry. Thus, it is necessary to select proper criteria applicable to the automotive industry which is the case study of this project. In this study, the expert view from the Malaysian automotive industry will take into consideration for the selection of appropriate criteria. Figure 5 and Table 1 will be used as a basis of the AHP model for vendor selection criteria and alternatives.

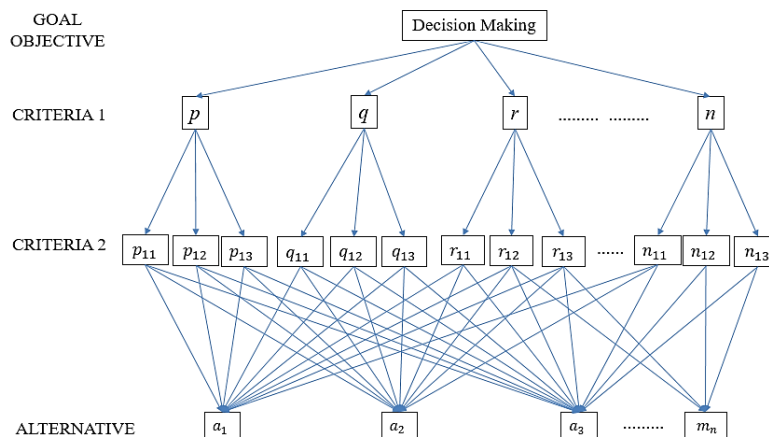


Figure 5. AHP model for structuring the vendor selection.

Table 1. Tabulation of criteria.

General Goal	Decision making											
Criteria 1	p			q			r			n		
Criteria 2	p ₁₁	p ₁₂	p ₁₃	q ₁₁	q ₁₂	q ₁₃	r ₁₁	r ₁₂	r ₁₃	n ₁₁	n ₁₂	n ₁₃

ii. Stage 2 is to determine the weight of each criterion

Measuring the relative importance of the criteria to the overall goal is the target of vendor selection. Therefore, the weight of each criterion is calculated by the following procedure: 1. Formulation of pairwise comparison matrix, 2. Normalization of pairwise comparison matrix, 3. Computation of weight, 4. Computation of weights for sub-criterion based on each main criterion, and 5 Consistency Test. Criteria in the same level are compared qualitatively among each other with two at a time in the pairwise comparison matrix form as shown in matrix A_{main} . The criteria are then judged on which one influences or is influenced more by using the fundamental Saaty scale of AHP [32].

Let matrix $A_{main} = [a_{ij}]; 1 \leq i, j \leq m$

$$[A_{main}] = \begin{matrix} & C_1 & C_2 & C_3 & \dots & C_m \\ \begin{matrix} C_1 \\ C_2 \\ C_3 \\ \vdots \\ C_m \end{matrix} & \begin{bmatrix} 1 & \frac{1}{a_{21}} & \frac{1}{a_{31}} & \dots & \frac{1}{a_{m1}} \\ a_{21} & 1 & \frac{1}{a_{32}} & \dots & \frac{1}{a_{m2}} \\ a_{31} & a_{32} & 1 & \dots & \frac{1}{a_{m3}} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & a_{m3} & \dots & 1 \end{bmatrix} \end{matrix} \quad (1)$$

where m = number of main criteria, C_m = main criteria, a_{ij} = Pairwise comparison of i th and j th criteria using the fundamental Saaty scale of AHP. The pairwise comparison matrix is then normalized as shown below.

$$[N_{main}] = \begin{bmatrix} N_{11} & N_{12} & N_{13} & \dots & N_{1m} \\ N_{21} & N_{22} & N_{23} & \dots & N_{2m} \\ N_{31} & N_{32} & N_{33} & \dots & N_{3m} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ N_{m1} & N_{m2} & N_{m3} & \dots & N_{mm} \end{bmatrix} \quad (2)$$

where N_{ij} is the normalized element of matrix A_{main} ; $N_{ij} = \frac{a_{ij}}{T_j}$, $T_j = \sum_{i=1}^m a_{ij}$, $1 \leq j \leq m$

Then, the weight of sub-criteria in the same level are arranged according to their main criteria, C_m in the first column of $n \times m$ matrix, W_{sub} .

$$[W_{sub}] = \begin{bmatrix} WS_{11} & 0 & 0 & \dots & 0 \\ WS_{21} & 0 & 0 & \dots & 0 \\ WS_{31} & 0 & 0 & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ WS_{n1} & 0 & 0 & \dots & 0 \end{bmatrix} \quad (3)$$

where, n is the number of sub-criteria.

iii. Stage 3 is determining vendor weight

It is to determine the vendor's weight based on all the bottom level criteria, which are sub-criteria calculated in a similar manner as the calculating weight of criteria, which is shown in stage 2. Then, the weights for vendors under different sub-criteria in the same level are arranged as shown in Eq. (4), with its column representing the weight of vendors under the same sub-criterion.

$$[W_{alt}] = \begin{bmatrix} WA_{11} & WA_{12} & WA_{13} & \dots & WA_{1n} \\ WA_{21} & WA_{22} & WA_{23} & \dots & WA_{2n} \\ WA_{31} & WA_{32} & WA_{33} & \dots & WA_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ WA_{v1} & WA_{v2} & WA_{v3} & \dots & WA_{vn} \end{bmatrix} \quad (4)$$

where, v is the number of alternatives or vendors

The following steps are followed and repeated for each pairwise comparison to check its consistency.

$$[A_{main}][W_{main}] = [P] \quad (5)$$

$$\begin{bmatrix} 1 & \frac{1}{a_{21}} & \frac{1}{a_{31}} & \dots & \frac{1}{a_{m1}} \\ a_{21} & 1 & \frac{1}{a_{32}} & \dots & \frac{1}{a_{m2}} \\ a_{31} & a_{32} & 1 & \dots & \frac{1}{a_{m3}} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & a_{m3} & \dots & 1 \end{bmatrix} \begin{bmatrix} WM_1 \\ WM_2 \\ WM_3 \\ \vdots \\ WM_m \end{bmatrix} = \begin{bmatrix} P_1 \\ P_2 \\ P_3 \\ \vdots \\ P_m \end{bmatrix} \quad (6)$$

$$max = \left(\frac{\frac{P_1}{WM_1} + \frac{P_2}{WM_2} + \frac{P_3}{WM_3} + \dots + \frac{P_m}{WM_m}}{m} \right) \quad (7)$$

$$Consistency\ Index, CI = \frac{(\lambda_{max} - m)}{(m - 1)} \quad (8)$$

Random indexes (RI) have been approximated by Saaty for various matrix sizes, m , as shown in Table 2 [31].

Table 2. Random indexes.

m	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

$$\text{Consistency Ratio, } CR = \frac{CI}{RI} \tag{9}$$

If the $CR \leq 0.10$, judgements in the pairwise comparison matrix are acceptable. Conversely, if the $CR > 0.1$, the most inconsistency judgement in the pairwise comparison matrix has to change to a plausible value to improve consistency.

iv. Stage 4 is to rank the vendors based on the overall score

The overall matrix $[O]$ or overall priority matrix is calculated by the following formula.

$$[O] = [W_{alt}][W_{sub}][W_{main}] \tag{10}$$

$$\begin{bmatrix} O_1 \\ O_2 \\ O_3 \\ \vdots \\ O_v \end{bmatrix} = \begin{bmatrix} WA_{11} & WA_{12} & WA_{13} & \dots & WA_{1n} \\ WA_{21} & WA_{22} & WA_{23} & \dots & WA_{2n} \\ WA_{31} & WA_{32} & WA_{33} & \dots & WA_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ WA_{v1} & WA_{v2} & WA_{v3} & \dots & WA_{vn} \end{bmatrix} \begin{pmatrix} \begin{bmatrix} WS_{11} & 0 & 0 & \dots & 0 \\ WS_{21} & 0 & 0 & \dots & 0 \\ WS_{31} & 0 & 0 & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ WS_{n1} & 0 & 0 & \dots & 0 \end{bmatrix} \begin{bmatrix} WM_1 \\ WM_2 \\ WM_3 \\ \vdots \\ WM_m \end{bmatrix} \end{pmatrix} \tag{11}$$

The rows in the overall matrix represent the overall score of each vendor and rank from highest to lowest score.

SUPPLY CHAIN OUTSOURCING FOR BIW MODULES

The scope of the study is mainly the outsourcing selection process of BIW modules and sub-modules. The preliminary analysis of BIW module structure is essential in order to meet the supply chain network. This is to meet the supply chain requirement in order to promote local vendors to participate in the industry. The production cost is higher in the case of in-house production of automotive parts due to high operating expenditure. Furthermore, outsourcing BIW modules is part of supporting the supply chain strategy. In an automotive plant, BIW production assembly process comprises modular assembly, sub-modular assembly and non-modular component assembly. These elements are welded together using resistance spot welding, arc welding, weld nut and stud weld. The main BIW component is underfloor, comprised of; 1. Front end module, 2. Front floor module, and 3. Rear floor module.

BIW is designed to comprise different module, sub-module and components to ease the assembly process. All of these elements are assembled together using various equipment and joint methods such as usage of robotic system, combination of jigs and fixtures and conveyor system. Spot welding is the most common method of joining the components to become a module and, finally the construction of complete BIW. Figure 6 illustrates the module of Front Side Member, which consists of assembly sub-module of 1. Sub-module A, 2. Sub-module B and 3. Sub-module C. The assembly location can be determined by segregating the assortment structure of BIW modules. The segregation of BIW modules and sub-modules is a method to ease vendor selection.

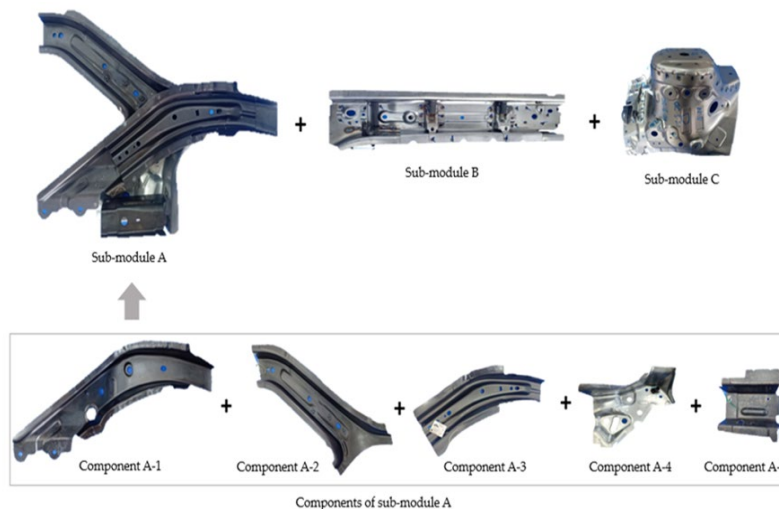


Figure 6. Sub-module and components structure of sub-module A.

DATA ANALYSIS

The objective or general goal of this analysis is to select a suitable vendor to produce the modular sub-assembly sub-module A, sub-module B and sub-module C for automotive BIW sub-modules. In this study, we consider four criteria (criteria 1) and thirteen sub-criteria (criteria 2), as explained in the following paragraph. Based on the literature and discussion with industrialist, criteria 1 for assessment consists of; 1) Company performance, 2) Product capability, 3) R&D capability and 4) Financial capability. Each of criteria have another sub-criterion.

As for criteria company performance, it consists of four sub-criteria; 1) Quality performance, 2) Delivery performance, 3) Capacity performance, and 4) Competitive advantage. Criteria product capability consists of; 1) Lead time and schedule, 2) Product specification and 3) Material specification. Criteria in R&D capability consists of; 1) Partnership or joint venture (JV), 2) Technical collaboration and 3) Infrastructure. Finally, criteria in financial capability consists of; 1) Financial availability, 2) Joint venture and 3) Collaboration.

Five alternatives established as a candidate. Alternative 1 is vendor A. Alternative 2 is vendor B, Alternative 3 is vendor C, Alternative 4 is vendor D and Alternative 5 is vendor E. Figure 7 shows the tabulation of the criteria, sub-criteria and alternatives. The criteria mentioned earlier was discussed with the industrial expert and managers in the Malaysian automotive industry.

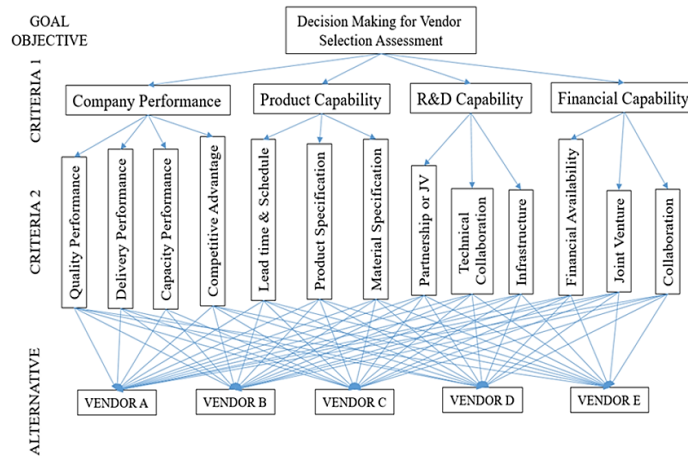


Figure 7. The analytic hierarchy process (AHP) model.

i. Pairwise weightage comparison computation

Collected data regarding pairwise comparison judgments, weights of main criteria, sub-criteria and vendors, and the overall score of vendors from the Excel-based AHP model are shown in this section. Calculation steps of normalization, computation of weights, consistency test for main criteria and overall score of vendors are shown in this section. Based on Table 3, value 3 is assigned to a cell where company performance is compared to product capability. Therefore, company performance is moderately important to product capability. Conversely, value 0.3333 or 1/3 is assigned to a cell where product capability is compared to company performance. Product capability is moderately important to financial capability. Financial capability has the highest priority among the five main criteria in vendor selection since it has the highest weightage of 0.4113.

Table 1. Pairwise comparisons of main criteria.

Main criteria	Company performance	Product capability	R&D capability	Financial capability	Weights
Company performance	1.0000	3.0000	5.0000	1.000	0.3800
Product capability	0.3333	1.0000	3.0000	0.3333	0.1475
R&D capability	0.2000	0.3333	1.0000	0.1429	0.0612
Financial capability	1.0000	3.0000	7.0000	1.0000	0.4113

Note: CR Value = 0.0122

ii. Normalization computation and consistency test

The input values from Table 2 were normalized by using Equation (2). The weight of main criteria was calculated by using Eq. (3). The result of normalization computation is in Table 3.

Using Eq. (2) to normalize the pairwise comparison matrix,

$$[N_{main}] = \begin{bmatrix} 0.3947 & 0.4091 & 0.3125 & 0.4038 \\ 0.1316 & 0.1364 & 0.1875 & 0.1346 \\ 0.0789 & 0.0455 & 0.0625 & 0.0577 \\ 0.3947 & 0.4091 & 0.4375 & 0.4038 \end{bmatrix}$$

Using Eq. (3) to determine the weights of main criteria,

$$[W_{main}] = \begin{bmatrix} \frac{0.3947 + 0.4091 + 0.3125 + 0.4038}{4} \\ \frac{0.1316 + 0.1364 + 0.1875 + 0.1346}{4} \\ \frac{0.0789 + 0.0455 + 0.0625 + 0.0577}{4} \\ \frac{0.3947 + 0.4091 + 0.4375 + 0.4039}{4} \end{bmatrix} = \begin{bmatrix} 0.3800 \\ 0.1475 \\ 0.0612 \\ 0.4113 \end{bmatrix}$$

Using Eq. (4) to Eq. (9) for consistency test,

$$[A_{main}][W_{main}] = [P]$$

$$\begin{bmatrix} 1 & 3 & 5 & 1 \\ \frac{1}{3} & 1 & 3 & \frac{1}{3} \\ \frac{1}{5} & \frac{1}{3} & 1 & \frac{1}{7} \\ 1 & 3 & 7 & 1 \end{bmatrix} \begin{bmatrix} 0.3800 \\ 0.1475 \\ 0.0612 \\ 0.4113 \end{bmatrix} = \begin{bmatrix} 1.5396 \\ 0.5947 \\ 0.2451 \\ 1.6619 \end{bmatrix}$$

$$\lambda_{max} = \left(\frac{1.5396 + 0.5947 + 0.2451 + 1.6619}{4} \right) = 4.0329$$

$$Consistency\ Index, CI = \frac{(4.0329 - 4)}{(4 - 1)} = 0.0110$$

$$Consistency\ Ratio, CR = \frac{0.0110}{0.90} = 0.0122 < 0.1$$

Therefore, the consistency test is considered pass since its CR value is less than 0.1.

Table 2. Normalized Matrix for Main Criteria

Criteria 1	Company performance	Product capability	R&D capability	Financial capability	Weights
Company performance	0.3947	0.4091	0.3125	0.4038	0.3800
Product capability	0.1316	0.1364	0.1875	0.1346	0.1475
R&D capability	0.0789	0.0455	0.0625	0.0577	0.0612
Financial capability	0.3947	0.4091	0.4375	0.4038	0.4113

Note: CR Value = 0.012

As a summary of the computation Table 4 show the result of all criteria 1 and criteria 2 as well as all the alternative local weight. All weights were converted into matrices [Walt], [Wsub] and [Wmain] before calculating overall score of vendors using Eq. (11).

iii. Local weight allocation analysis

The weights of vendors based on all the bottom level criteria, which are sub-criteria are calculated in a similar manner as calculating weight of criteria. Then, the weights for vendors under different sub-criteria in the same level are arranged with its column representing the weight of vendors under the same sub-criterion as shown in Table 5.

Weight of vendors in matrix form

$$[W_{alt}] = \begin{bmatrix} 0.3235 & 0.4085 & 0.3538 & 0.3580 & 0.2289 & 0.6421 \\ 0.3235 & 0.1806 & 0.1890 & 0.1904 & 0.1956 & 0.0803 \\ 0.0758 & 0.1151 & 0.1890 & 0.1682 & 0.2289 & 0.0703 \\ 0.1368 & 0.1151 & 0.1235 & 0.1682 & 0.1733 & 0.0971 \\ 0.1368 & 0.1806 & 0.1446 & 0.1152 & 0.1733 & 0.1103 \end{bmatrix}$$

$$\begin{bmatrix} 0.5264 & 0.4039 & 0.3083 & 0.4039 & 0.2644 & 0.3235 & 0.2800 \\ 0.0755 & 0.0951 & 0.1931 & 0.1543 & 0.2094 & 0.3235 & 0.3245 \\ 0.1053 & 0.1475 & 0.1281 & 0.1543 & 0.1172 & 0.0758 & 0.1275 \\ 0.1187 & 0.1346 & 0.2075 & 0.0983 & 0.2044 & 0.1386 & 0.0954 \\ 0.1748 & 0.2190 & 0.1631 & 0.1892 & 0.2044 & 0.1386 & 0.1726 \end{bmatrix}$$

Weight of sub-criteria in matrix form

$$[W_{sub}] = \begin{bmatrix} 0.4072 & 0 & 0 & 0 & 0 \\ 0.2753 & 0 & 0 & 0 & 0 \\ 0.0722 & 0 & 0 & 0 & 0 \\ 0.2453 & 0 & 0 & 0 & 0 \\ 0.2431 & 0 & 0 & 0 & 0 \\ 0.0882 & 0 & 0 & 0 & 0 \\ 0.6687 & 0 & 0 & 0 & 0 \\ 0.6270 & 0 & 0 & 0 & 0 \\ 0.0807 & 0 & 0 & 0 & 0 \\ 0.2923 & 0 & 0 & 0 & 0 \\ 0.2605 & 0 & 0 & 0 & 0 \\ 0.1062 & 0 & 0 & 0 & 0 \\ 0.6333 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Weight of main criteria in matrix form

$$[W_{main}] = \begin{bmatrix} 0.3800 \\ 0.1475 \\ 0.0612 \\ 0.4113 \end{bmatrix}$$

Using Eq. (5) and Eq. (6) to calculate the overall score of vendors,

$$[O] = [W_{alt}][W_{sub}][W_{main}]$$

$$\begin{bmatrix} O_1 \\ O_2 \\ O_3 \\ O_4 \\ O_5 \end{bmatrix} = \begin{bmatrix} 0.3440 \\ 0.2358 \\ 0.1223 \\ 0.1325 \\ 0.1654 \end{bmatrix} = \begin{bmatrix} \text{Vendor A} \\ \text{Vendor B} \\ \text{Vendor C} \\ \text{Vendor D} \\ \text{Vendor E} \end{bmatrix}$$

Table 3. Summary of local weights allocation.

Criteria 1	Criteria 2	Local weight of each vendor				
		Vendor A	Vendor B	Vendor C	Vendor D	Vendor E
Company performance 0.3800	Quality performance 0.4072	0.3235	0.3235	0.0758	0.1386	0.1386
	Delivery performance 0.2753	0.4085	0.1806	0.1151	0.1151	0.1806
	Capacity performance 0.0722	0.3538	0.1890	0.1890	0.1235	0.1446
	Competitive advantage 0.2453	0.3580	0.1904	0.1682	0.1682	0.1152
Product capability 0.1475	Time to market 0.2431	0.2289	0.1956	0.2289	0.1733	0.1733
	Product specification 0.0882	0.6421	0.0803	0.0703	0.0971	0.1103
	Material specification 0.6687	0.5264	0.0750	0.1053	0.1187	0.1748
R&D capability 0.0612	Partnership/ JV 0.6270	0.4039	0.0951	0.1475	0.1346	0.2190
	Technical collaboration 0.0807	0.3083	0.1931	0.1281	0.2075	0.1631
Financial capability 0.4113	Infrastructure 0.2923	0.4039	0.1543	0.1543	0.0983	0.1892
	Financial availability 0.2605	0.2644	0.2094	0.1172	0.2044	0.2044
	Joint venture 0.1062	0.3235	0.3235	0.0758	0.1386	0.1386
	Collaboration 0.6334	0.2800	0.3245	0.1275	0.0954	0.1726

RESULTS AND DISCUSSION

The computation of the result was developed by using VBA in Microsoft office Excel environment. The AHP method was applied in this vendor selection. The VBA codes programming had developed to automate the process of computation. The Microsoft Excel workbook consists of four sheets which are the VBA scripting has segregated into few modules. It is including, 1. Guidelines, 2. Input, 3. Table result and 4. Graphical result.

“Input” spreadsheet allows the user inserts few criteria and sub-criteria, and in normal practice the criteria are from 2 to 5 criteria involved in the evaluation. In this study, 3 to 4 criteria in assessment is considered. There are three main step of input data in this assessment; 1. Input the criteria and sub-criteria, 2. Input the vendor’s name, which maximum 10 vendors, and 3. Input the judgment based on Saaty’s scale for pairwise computation analysis as in Table 6.

Based on the computation of AHP analysis of sub-module Side Member Front Assembly for sub-module A, sub-module B and sub-module C, it is apparent the proposal or final decision is the vendor A. The outsource location of all the sub-modules assembly processes is proposed at the vendor A location based on the weightage of the pairwise comparison. This result was reviewed with a few industry experts, which involved the project procurement engineer. The result of AHP analysis indicates, it is completely agreed by the industrial expert and proposes using the same methodology for decision making of other projects.

Based on the main criteria, sub-criteria and alternatives established, the computation using AHP methodology finally yields the quantitative result. The result of vendor A is 0.3440, which is a higher weightage compared to vendor B; 0.2358, vendor C; 0.1223 vendor D; 0.1352 and vendor E; 0.1654. Vendor A agreed by all related parties in the industry as the best option for sub-module assembly process of modules in order to meet local contents strategy.

Table 1. User interface of pairwise comparison matrix in “input” spreadsheet.

STEP 3 Please enter judgements in the yellow fields of all pairwise comparison matrix tables using Saaty's scale (Refer Saaty's scale in "Guidelines")						
Pairwise Comparison Matrix for Main Criteria					CR Value = 0.012	Consistency Test = Pass
Main Criteria	Company Perform	Product Capability	R&D Capability	Financial Capability	Weight	
Company Performance	1.00	3.00	5.00	1.00	0.38004	
Product Capability	0.33	1.00	3.00	0.33	0.14751	
R&D Capability	0.20	0.33	1.00	0.14	0.06115	
Financial Capability	1.00	3.00	7.00	1.00	0.41129	
Pairwise Comparison Matrix for Company Performance					CR Value = 0.070	Consistency Test = Pass
Company Performance	Quality Performar	Delivery Performance	Capacity Perform	Competitive Advant	Weight	
Quality Performance	1.00	1.00	5.00	3.00	0.40720	
Delivery Performance	1.00	1.00	3.00	1.00	0.27533	
Capacity Performance	0.20	0.33	1.00	0.20	0.07221	
Competitive Advantage	0.33	1.00	5.00	1.00	0.24526	

Decision-making is crucial in the industry as the industry expert has a restriction to convey their experience to the management prior to the final decision making. Industry issues such as making decision of sub-module assembly parts and module production location in the automotive industry is one of the industry’s problem. The AHP methodology is proven as the appropriate tool for decision making in the industry. In daily operation in the industry, especially in the automotive environment, a lot of decision making is required. A simple qualitative measurement would benefit to engineers to make a proposal to the management with the quantitative result. The intuition of the expert would convey to the decision maker in the industry to reach a decision on the proposal.

The model was justified as the results from the computation analysis, as in Figure 8. Financial capability weighted 0.411 is the main criterion with the highest priority. Company performance is 0.380, product capability is 0.147, R&D capability is 0.06. As illustrated in Figure 9, quality performance weighted 0.407 is a sub-criteria with the highest priority based on their respective main criteria company performance. Delivery performance is 0.275, competitive advantages is 0.245 and capacity performance is 0.072. Figure 10 shows the result of computation for overall score of vendors which are presented in graphical format in “Graphical Result” spreadsheet. As a result, vendor A is the best vendor since it has the highest overall score of 0.35206. Whereas vendor B is 0.239, vendor C is 0.126, vendor D is 0.146 and vendor E 0.135.

To summarize, the VBA Microsoft Excel-based AHP model can be used on other sub-module for decision making process. VBA with Microsoft Excel-based AHP model for vendor selection was developed. The model is capable of receiving 10 or more main criteria and 10 vendors. Moreover, the model is able to compare 10 criteria/ sub-criteria/ vendors simultaneously. This VBA code programming is capable enough to fulfil the intended objective of the study.

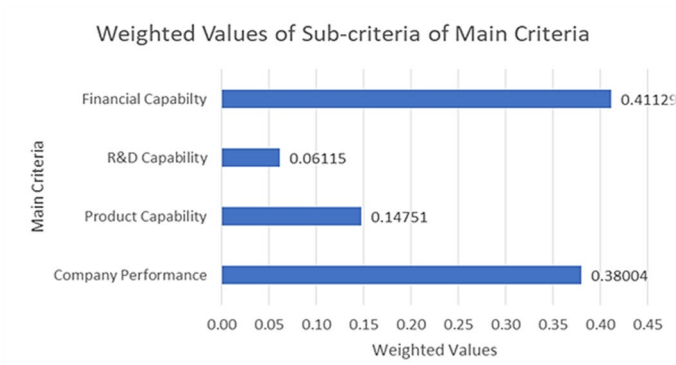


Figure 8. Weighted values of sub-criteria of main criteria result.

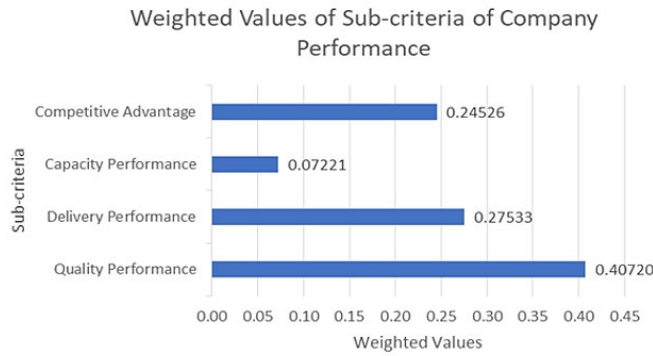


Figure 9. Weighted values of sub-criteria of company performance result.

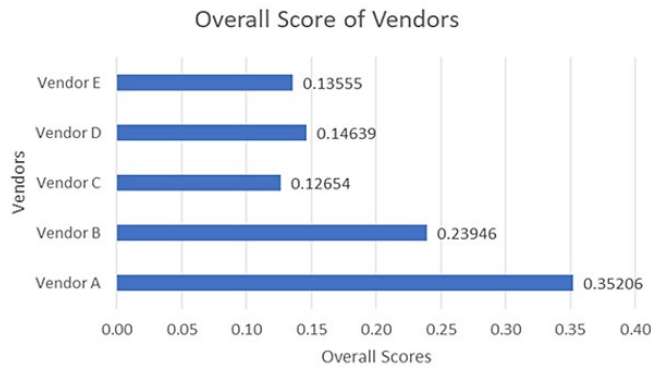


Figure 10. Overall score of vendor’s result.

CONCLUSION

In this research, component outsourcing was investigated for a case study in module components of BIW in the automotive industry. Module supply to the production assembly line is an important element of SCM practices and is considered to be a multi-criteria decision-making problem (MCDM) in vendor selection processes. The methodology applied was the development of an Excel-based Analytic Hierarchy Process (AHP) model for vendor selection. This is to help the industrialist to simplify the processes of vendor selection. Thus, this study provided a practical analysis of the AHP method using the VBA code programming, which assists industrialist in automating the selection process. Based on the result computation AHP method also proved that qualitative data can be converted into quantitative data. As the vendor selection analysis are vastly important in the automotive industry, the establishment of computation algorithm is essential contribution. The methodology & method of analysis able to compute and propose vendor A in the vendor selection to support the automotive localization initiative. Finally, the hands-on analysis for the vendor selection process is an essential tool in terms of industrial practice. This study covered the automated vendor selection process in supporting the effectiveness of SCM in the automotive industry.

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