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Article

Optimal Supplier Selection Model with Multiple Criteria: A Case Study in the Automotive Parts Industry

Naragain Phumchusri* **and Supasit Tangsiriwattana**

Department of Industrial Engineering, Faculty of Engineering, Chulalongkorn University, Pathumwan, Bangkok, Thailand
*E-mail: naragain.p@chula.ac.th

Abstract. This research proposes a mathematical model for supplier selection for a case-study car seat manufacturer. This research is divided into 2 parts. The first part is the raw material supplier evaluation method using Analytic Hierarchy Process. This part weights the importance of main decision criteria and sub-decision criteria, complying with part makers' satisfaction. The result from the first part is scores for each raw material supplier resulting from multiple evaluation criteria. The second part proposes a mathematical model for supplier selection using integer programming. The scores of each supplier from the first part will be considered along with raw material consumption to select the suitable raw material suppliers that maximize overall part makers' satisfaction. The results from the first part of this research show that the most important criterion for supplier evaluation is cost, which is about 41%. Quality, Delivery, Service, and Risk factors are approximately 24%, 14%, 12% and 9%, respectively. The result from the second part shows that the model can effectively match material suppliers to part makers according to their preferences. Comparing with current situation, the satisfaction is increased by 26% with this proposed framework. It means the proposed model can help matching the right supplier to each part maker that can increase overall satisfactions for this case-study's supply chain.

Keywords: Suppliers selection, analytic hierarchy process, integer programming, automotive parts industry, manufacturing supply chain, supply chain management.

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1. Introduction

Supplier selection is one of the most important strategies for inbound supply chain management. For automotive industry, vehicle seat is one of the important components that must be supplied to car makers. The case-study company we study in this research is a leading car seat manufacturer in Thailand, having a number of part makers as their direct suppliers. However, each part maker also has many potential raw material suppliers. These suppliers can be classified into 2 mutually exclusive groups: pipe makers and sheet makers. The selection of part makers' suppliers affects the overall performance of the car seats materials supplied to the case-study company. After car seats are manufactured, they will be supplied to car makers who assembly all parts at the final stage of the automotive supply chain. Figure 1 presents an example of car seats supply chain considered in this paper.

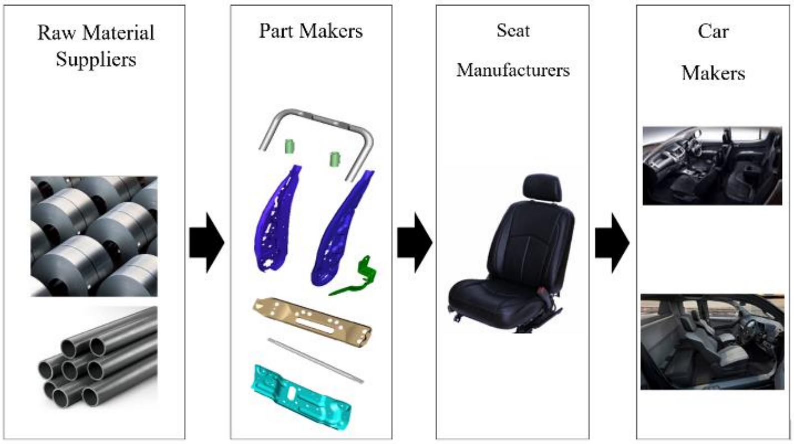

Fig. 1. Example of car seats supply chain.

For each car seat structure, there are many small part components which can be grouped into 13 parts, shown in Fig. 2. They are (1) bracket headrest holder, (2) upper pipe frame front back, (3) side frame front back, (4) rear pipe frame front cushion, (5) regular lever, (6) side frame front cushion, (7) slide adjuster, (8) adjuster rod, (9) bracket leg, (10) front panel cushion, (11) connecting rod, (12) lower panel frame front back, and (13) top panel frame front back.

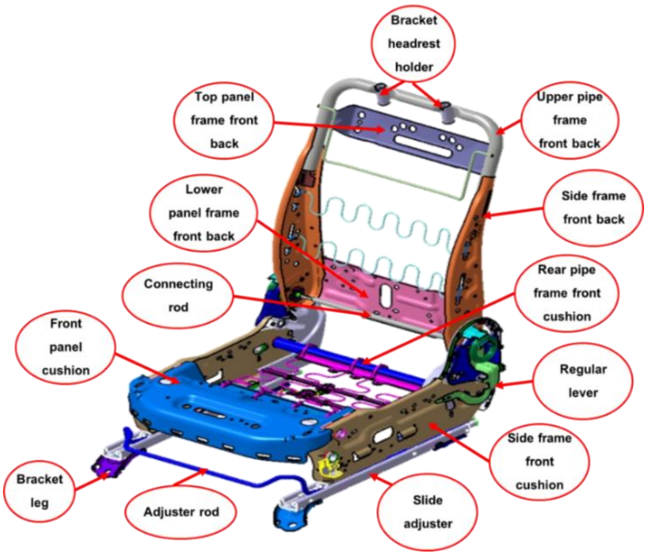

Fig. 2. Car seat structure components.

In the past, the case-study manufacturers allowed each part maker to independently select steel pipe and steel sheet suppliers. With these independent decisions, each part maker may have different preferences. Some part makers order materials from the same suppliers for multiple years for the convenience of purchasing activities. Some part makers change suppliers according to only one factor, e.g., price. In the past year, there were many problems about material qualities and deliveries, which are caused by inappropriate selection of material suppliers. Thus, this paper proposes a model for evaluating steel pipe and steel sheet suppliers for part makers, by applying Analytic Hierarchy Process (AHP), and a decision model for selecting the suitable raw material supplier for each part maker.

The first part of this research presents evaluation method using Analytic Hierarchy Process (AHP). The criteria considered are selected by evaluators from purchasing management team from all ten part makers. They are cost, quality, delivery, service, and risk management. The reason that it is necessary to evaluate all five criteria is that some material suppliers may offer low cost, but at the same time have low after sale service quality. Taking all criteria into account will help the case-study manufacturer to understand all characteristics of material suppliers. The second part presents an integer programming model for supplier selection that considers the weight of each criterion obtained from the first part of this research. This model aims to maximize overall part makers' satisfaction. This is because the higher part makers' satisfaction, the higher performance of the parts supplied by them.

This paper is organized as follows. In section 2, we provide a review of related literature. In section 3, we explain research methodology for each part. Then, in section 4, we present results obtained by applying the presented methodology to the case-study manufacturer. In section 5, we finally conclude the important points obtained from this research as well as interesting points that can be extended as future work.

2. Literature Review

Analytic Hierarchy Process (AHP) is a multi-criteria decision-making technique for analyzing complex decisions. It was developed by Saaty to assist in solving complex decision making by considering both subjective and objective evaluation measurement [1]. Figure 3 shows three levels of hierarchy for the AHP. The first, second and third levels are goal, criteria & sub-criteria, and alternative, respectively. AHP applies a pair-wise comparison of the criteria importance with respect to the goal. Thus, it allows finding the relative weight of one criterion as compared to the main goal.

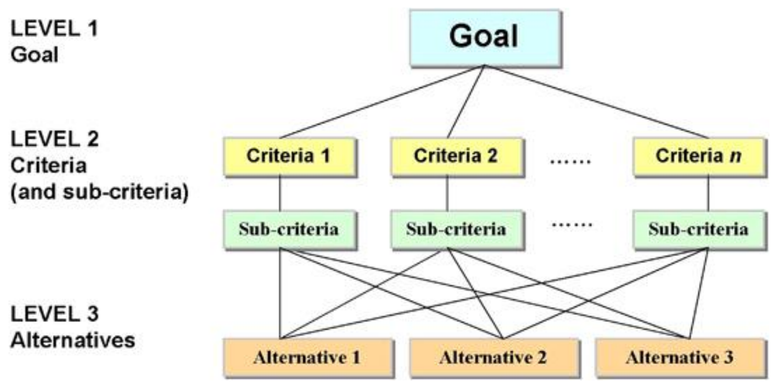

Fig. 3. Structure of levels in Analytic Hierarchy Process.

Among a variety of decisions that can apply AHP to help making analysis, supplier selection is one of them. Houshyar and Lyth [2] proposed a systematic procedure for supplier selection, in which their model included all the relevant factors into the decision, and classified them into critical factors, objective factors, and subjective factors. They also provided a procedure that can be used to evaluate the supplier's performance. Akarte et al. [3] identified 18 criteria for casting supplier assessment and segregated in four groups. They developed a systematic approach to evaluating casting quality suppliers using the analytical hierarchy process, which enables the combination of tangible and intangible criteria and checking the consistency of decision-making. Yu and Tsai [4] developed a framework integrating the AHP and integer programming to rate suppliers' performance regarding incoming raw materials in the context of supplier management, using a case study of the semiconductor industry. They found that the rating weights of primary criteria and sub-criteria for each supplier should be flexibly considered in peak and off seasons to meet actual requirements. Chen and Wu [5] proposed a modified failure mode and effects analysis (MFMEA) method to select new suppliers from the supply chain risk's perspective and applied AHP to find the weight of each criterion and sub-criterion for supplier selection. Other research that applied AHP in supplier selection can be found in Kahraman et al. [6], Percin [7], Dai and Blackhurst [8], Deng et al. [9], Zhang et al. [10] and Secundo et al. [11].

There are a number of research that proposed alternative approach for supplier selection other than AHP. Research on supplier selection problem that combines lot sizing and supplier choice decisions together are developed by Kasilingam and Lee [12] and Jayaraman et al. [13]. Both presented mixed-integer programming models for supplier selection and determine the lot size of the products. Later, Dahel [14] developed a multi objective mixed integer programming approach to select the number of suppliers to source and the lot size of each product to order to suppliers for a multiproduct, multi-supplier competitive sourcing environment. Lin and Lin [15] developed a fuzzy analytic hierarchy process to identify significant criteria for selection of raw material suppliers by Taiwanese processors of the dried roe of striped mullet Mugil cephalus. They found that while price and quality were considered to be given priority, the ability to meet delivery due dates and time to market, which were critical factors in most previous supplier selection research, were found to be insignificant. Hsu et al. [16] proposed the quality-based supplier selection with fuzzy quality data. They applied the resolution identity result (a well-known method used in fuzzy sets theory) in terms of solving the nonlinear programming problems with bounded variables to construct the membership function of a fuzzy capability-index estimate for each supplier.

Shi et al. [17] presented a basic selection process of green suppliers and developed a systematic data envelopment analysis (DEA) approach that is quantitative to evaluate and select green suppliers using the C2R model of the DEA method and the super-efficiency DEA model, which is based on the C2R model. Their model is used for evaluating and selecting suppliers under the sustainable supply chain environment. Mohammaditabar and Ghodsypour [18] developed a model in capacity-constrained supplier-selection and order-allocation problem, which considered the joint replenishment of inventory items with a direct grouping approach. Lot-sizing with supplier selection (LS-SS) is a fast-growing offspring of two major problem parents in logistics and supply chain management. Razaei et al. [19] proposed an attempt to extend these ideas to an assembly system, by formulating a multi-objective model for an integrative problem of LS-SS for assembly items. Other related works can be found in Saen [20], Rodriguez, et al. [21], Abdollahi et al. [22] and Moghaddam [23].

In automotive supply chain, sourcing decision can plan important role in the overall performance of the supply chain. Schmitz and Platts [24] presented a brief discussion of the literature on inter-organizational performance measurement and contrast existing concepts of intra-organizational performance measurement with the concepts of performance measurement within an automotive supply chain. Schmitz and Platts [25] proposed indications from a study of five vehicle manufacturers in Europe according to their practices of supplier evaluation in the area of logistics. They developed a conceptual framework describing the roles of supplier performance measurement in a context of categorization of functions of intra-organizational performance measurement. Blackhurst et al. [26] developed a supplier risk assessment methodology for measuring, tracking, and analyzing supplier and part specific risk over time for an automotive manufacturer. Their work was claimed to be dynamic risk analysis methodology that cab analyze and monitor supplier risk levels over time. Ghadimi et al. [27] proposed a comprehensive framework to address the sustainable supplier selection and order allocation problem for automotive industry.

While most of the literature mentioned above are related to evaluating direct suppliers, this paper focuses on applying AHP to indirect suppliers (which are suppliers of suppliers). Thus, the evaluation methodology will be designed for the case-study's suppliers to evaluate their suppliers in the automotive supply chain for each criterion. We integrate AHP and integer programming model to identify the most suitable suppliers for each part, subject to required constraints that the case-study company would like to keep as many suppliers as possible in the supply chain. Then we show that the developed algorithm can significantly increase overall satisfactions of parties in this supply chain.

3. Methodology

There are two main parts in this research. The first part is the evaluation of raw material suppliers using Analytic Hierarchy Process in order to obtain the overall performance of each supplier by considering all relevant decision criteria complying with part makers' satisfaction. The second part is a model for supplier section for each material part using integer programming. The methodology of this paper is as follows: (1) study of the case-study manufacturer's current process, (2) data collection, (3) criteria identification, (4) supplier selection model development, (5) result evaluation and (6) conclusion.

3.1. Analytic Hierarchy Process for Supplier Evaluation

The case-study manufacturer has 10 part makers as their direct suppliers. Each part maker has its own raw material suppliers. In this process, the evaluators are chosen from purchasing management team from 10 part makers. These assessors will evaluate their 8 raw material suppliers (which are divided into two groups: steel sheet and steel pipe suppliers) in this car seat manufacturing industry. From intensive interview, the evaluators have selected 5 main criteria in which they consider to be the most important issues: (1) quality (2) cost (3) delivery performance (4) service and (5) risk. For each criterion, there are sub-criteria that are considered to be important.

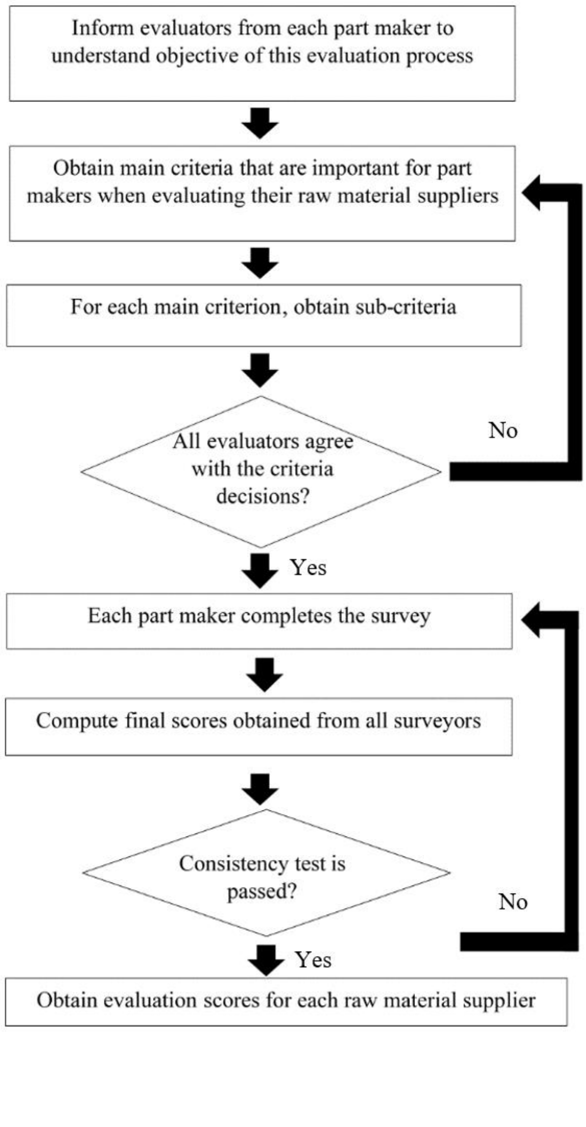

Fig. 4. Evaluation process.

Figure 4 shows steps in this evaluation process. First, the evaluators from each part maker are informed about our methodology so that they understand the objective of this process. The intensive interviews are conducted in obtain the main criteria that are important for part makers when they evaluate their raw material suppliers. After obtaining the main criteria, the sub-criteria for each main criterion are obtained from another interview. The sub-criteria for each main criterion obtained from the evaluators are shown in Table 1.

Each criterion is paired with the other until it meets all possible pairs. This process of pair-wise comparison is used to find the relative importance of the alternatives with respect to each of the criteria. Each criterion will be compared with its pair to get the scores (1 to 9), representing comparative importance of each one compared to the other. In some criteria, although the 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 [1] as shown in Table 2. According the AHP methodology, each child has a local and global priority with respect to the parent. The summation 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. From evaluators' survey results, Table 3 shows comparative scores for each pair of main criteria.

Table 1. Sub-criteria for each criterion.

Main criteria	Sub-criteria
Quality	Ability to meet order requirement Ability to meet quality requirement Quality of packaging Quality consistency Quality guarantee Final checking of quality before delivery Having suppliers with high credibility
Cost	Reasonable price for each material supplied Willingness to reduce price Flexibility for negotiation Credit time
Delivery	Ability to deliver at the committed time and quantity Correct delivery documents Reasonable minimum delivery order Drivers manner Active response when delays occur No shortage of suppliers Delivery flexibility
Service	Sales response time Action response time when there are material problems Available consultants when needed New raw material examples available for R&D testing
Risk	Company overall financial credibility Ability to meet legal environmental requirement Location Business loyalty Supply chain resilience

Table 2. Important scale in pair-wise comparison.

Importance scale	Description
1	Equal importance for *a* and *b*
3	Weak importance of *a* over *b*
5	Strong importance of *a* over *b*
7	Very strong importance of *a* over *b*
9	Absolute importance of *a* over *b*

Note: 2,4,6, and 8 are intermediate values.

Table 3. Comparative scores for each pair of criteria.

Decision Criteria	Quality	Cost	Delivery	Service	Risk
Quality	1	1/3	3	3	2
Cost	3	1	4	3	3
Delivery	1/3	1/4	1	2	2
Service	1/3	1/3	1/2	1	2
Risk	1/2	1/3	1/2	1/2	1
Sum of column	5.17	2.25	9	9.5	10

After each part maker completes the survey, Table 4 shows AHP normalized scores obtained for each criterion. It is observed that cost is the most important issue with score of 41%. Then, they are quality, delivery, service, and risk management with scores of 24%, 14%, 12% and 9%, respectively.

Table 4. AHP normalized scores for each criterion.

Decision Criteria	Quality	Cost	Delivery	Service	Risk	Sum of row	Eigen vector (weight)
Quality	0.194	0.148	0.333	0.316	0.200	1.190	0.24
Cost	0.581	0.444	0.444	0.316	0.300	2.090	0.41
Delivery	0.065	0.111	0.111	0.211	0.200	0.700	0.14
Service	0.065	0.148	0.056	0.105	0.200	0.57	0.12
Risk	0.097	0.148	0.056	0.053	0.100	0.45	0.09
Sum of column	1.00	1.00	1.00	1.00	1.00	5.00	1.00

From the scores above, the consistency vector for each criterion can be computed as followed.

- Consistency vector of quality = [(1.00x0.24) + (0.33x0.41) + (3.00x0.14) + (3.00x0.12) + (2.00x0.09)] / 0.24 = 5.56
- Consistency vector of price = [(3.00x0.24) + (1.00x0.41) + (4.00x0.14) + (3.00x0.12) + (3.00x0.09)] / 0.41 = 5.66
- Consistency vector of delivery = [(0.33x0.24) + (0.25x0.41) + (1.00x0.14) + (2.00x0.12) + (2.00x0.09)] / 0.14 = 5.30
- Consistency vector of service = [(0.33x0.24) + (0.33x0.41) + (0.50x0.14) + (1.00x0.12) + (2.00x0.09)] / 0.12 = 4.87
- Consistency vector of risk = [(0.50x0.24) + (0.33x0.41) + (0.50x0.14) + (0.50x0.12) + (1.00x0.09)] / 0.09 = 5.28

The maximum eigenvalue and consistency index (C.I.) can be computed by:

$$Maximums\ eigenvalue(\lambda_{max}) = \frac{\sum Eigenvalue}{Number\ of\ criteria} = \frac{26.67}{5} = 5.33 \tag{1}$$

and

$$C.I. = \frac{(\lambda_{max} - n)}{(n-1)} = \frac{(5.33-5)}{(5-1)} = 0.08 \tag{2}$$

Random inconsistency Index (R.I.) and consistency ratio (C.R.) are as followed:

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$$R.I. = 1.12$$

$$C.R. = \frac{C.I.}{R.I.} = \frac{0.08}{1.12} = 0.071 \quad (3)$$

The pair-wise comparison is performed to check the consistency of the result. Since C.R. = 0.071 < 0.10, there is no problem of inconsistency from the result and it is valid to apply the result to the next step. Next, the evaluation score for each raw material supplier for supplying each part is obtained using the concept presented in Fig. 5.

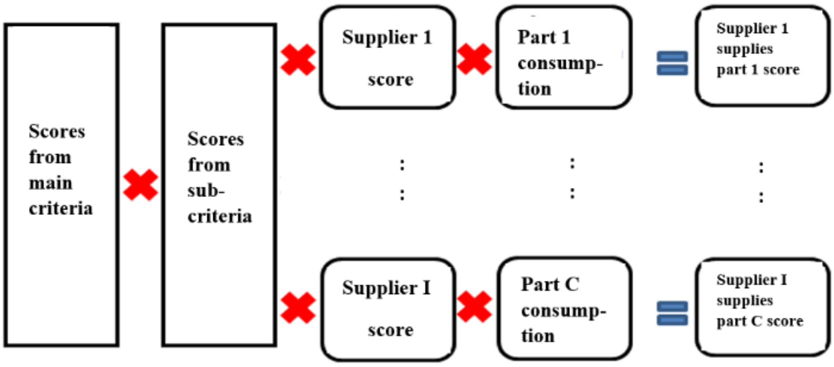

Fig. 5. Evaluation score for each supplier for supplying each part.

3.2. Integer Programing Model for Supplier Selection

In this second part of the research, the decision model is developed using integer programing method. The objective is to choose the right raw material supplier for each part to maximize their overall satisfaction with respect to the case-study company's required constraints. Let decision variables X_{ic} be 1 if steel sheet supplier c is chosen to supply part number i (0 otherwise) and Y_{jp} be 1 if steel pipe supplier p is chosen to supply part number j (0 otherwise). Note that i and j represent part number that requires steel sheet and steel pipe, respectively, where $i = \{1, \dots, I\}$, and j = $\{1, \dots, J\}$. Let c and p represent the steel sheet and steel pipe supplier, respectively, where $c = \{1, \dots, C\}$ and $p = \{1, \dots, P\}$.
The objective function can be written as followed:

$$Max \quad Z = \sum_{i=1}^{I} \sum_{c=1}^{C} a_{ic} X_{ic} + \sum_{j=1}^{J} \sum_{p=1}^{P} b_{jp} Y_{jp} \quad (4)$$

where a_{ic} is satisfaction score that steel sheet supplier c received from supplying sheet part number i and b_{jp} is score that steel pipe supplier p received from supplying pipe part number j (in the evaluation process described in the previous section). Below are constraints for this case-study company:

1) There is only one steel sheet supplier for each sheet part number:

$$\sum_{c=1}^{C} X_{ic} = 1 \quad ; \forall i \quad (5)$$

2) There is only one steel pipe supplier for each pipe part number:

$$\sum_{p=1}^{P} Y_{jp} = 1 \quad ; \forall j \quad (6)$$

3) If $I > C$, the case-study manufacturer would like to keep each of supplier in the network. So, each steel sheet supplier must be chosen to supply at least one sheet part number:

$$\sum_{i=1}^{I} X_{ic} \geq 1 \quad ; \forall c \quad (7)$$

If $I \leq C$, the number of steel sheet suppliers is at most equal to the number of sheet parts. In this case, each supplier must be chosen to supply at most one sheet part number:

$$\sum_{i=1}^{I} X_{ic} \leq 1 \qquad ; \forall c \tag{8}$$

4) Similar idea applies to pipe suppliers. If $J > P$, the case-study manufacturer would like to keep each of supplier in the network. So, each steel pipe supplier must be chosen to supply at least one sheet part number:

$$\sum_{j=1}^{J} Y_{jp} \geq 1 \qquad ; \forall p \tag{9}$$

If $J \leq P$, each steel pipe supplier must be chosen to supply at most one sheet part number:

$$\sum_{j=1}^{J} Y_{jp} \leq 1 \qquad ; \forall p \tag{10}$$

5) The total cost obtained from this decision must not exceed the cost limit (L) (from the previous year's decision):

$$\sum_{i=1}^{I} \sum_{c=1}^{C} d_{ic} X_{ic} + \sum_{j=1}^{J} \sum_{p=1}^{P} e_{jp} Y_{jp} \quad \leq \quad L \tag{11}$$

where d_{ic} and e_{jp} are the cost for suppliers if they are chosen to supply sheet part number c and pipe part number p, respectively.

4. Results and Discussion

From the survey obtained from all part makers about their satisfaction scores for each material supplier, Table 5 and 6 summarize satisfaction score (a_{ic}) that steel sheet supplier c received from supplying sheet part number i. and score that steel pipe supplier p received from supplying pipe part number j, respectively.

After applying the methodology discussed in the previous section to the case-study company, the results from 10 part makers and 8 raw material suppliers (3 steel sheet suppliers and 5 steel pipe suppliers) are shown in Table 7. It can be observed that steel sheet supplier number 1 is chosen to supply the most number of parts. This is because the evaluation score for supplier number 1 from the first part of this research is the highest. Sheet supplier number 3 is chosen to supply only one part number (just to keep this supplier in the network) because the evaluation score from this supplier is very low. From Table 8, pipe supplier number 4 is not chosen to supply any because the number of parts is less than the number of suppliers, so the model chooses not to include supplier number 4 as its evaluation score is the lowest.

Comparing the case-study company's current decision to the result from the proposed model, it shows that the overall satisfaction can be increased from 30.15 to 37.86, which is about 26% increase from the current decision. After the result is obtained, the case-study company management has approved this new decision and suggested to apply this model the other 6 car seat number produced by this company. Table 9 displays the results of satisfaction score obtained from the proposed model for each car seat number, as compared the current decision. It can be seen that the proposed model can improve the overall satisfaction of the case-study company's part makers for every car seat model.

Table 5. Satisfaction score for each steel sheet supplier received from supplying each sheet part no.

Part no. i	**Percentage of monthly usage**	**Part maker**	**Steel Sheet Supplier c**	**Percentage of satisfaction**	**Decision variable**	**Satisfaction score (a_{ic})**
1	0.96	9	1	35	X_{11}	$a_{11} = 0.34$
			2	36	X_{12}	$a_{12} = 0.35$
			3	28	X_{13}	$a_{13} = 0.27$
2	1.28	1	1	30	X_{21}	$a_{21} = 0.38$
			2	41	X_{22}	$a_{22} = 0.52$
			3	29	X_{23}	$a_{23} = 0.38$
3	1.40	4	1	39	X_{31}	$a_{31} = 0.55$
			2	33	X_{32}	$a_{32} = 0.47$
			3	28	X_{33}	$a_{33} = 0.39$
4	4.34	5	1	41	X_{41}	$a_{41} = 1.79$
			2	33	X_{42}	$a_{42} = 1.42$
			3	26	X_{43}	$a_{43} = 1.12$
5	2.81	5	1	41	X_{51}	$a_{51} = 1.16$
			2	33	X_{52}	$a_{52} = 0.92$
			3	26	X_{53}	$a_{53} = 0.73$
6	1.28	10	1	39	X_{61}	$a_{61} = 0.50$
			2	38	X_{62}	$a_{62} = 0.49$
			3	23	X_{63}	$a_{63} = 0.29$
7	0.51	4	1	39	X_{71}	$a_{71} = 0.20$
			2	33	X_{72}	$a_{72} = 0.17$
			3	28	X_{73}	$a_{73}= 0.14$
8	4.47	4	1	39	X_{81}	$a_{81} = 1.75$
			2	33	X_{82}	$a_{82} = 1.48$
			3	28	X_{83}	$a_{83} = 1.23$
9	2.81	5	1	41	X_{91}	$a_{91} = 1.16$
			2	33	X_{92}	$a_{92} = 0.92$
			3	26	X_{93}	$a_{93} = 0.73$
10	31.91	7	1	45	X_{101}	$a_{101} = 14.15$
			2	24	X_{102}	$a_{102} =7.57$
			3	31	X_{103}	$a_{103} = 9.83$
11	19.15	4	1	39	X_{111}	$a_{111} = 7.51$
			2	33	X_{112}	$a_{112} = 6.34$
			3	28	X_{113}	$a_{113} = 5.29$
12	5.62	4	1	39	X_{121}	$a_{121} = 2.20$
			2	33	X_{122}	$a_{122} = 1.86$
			3	28	X_{123}	$a_{123} = 1.55$
13	5.11	4	1	39	X_{131}	$a_{131} = 2.00$
			2	33	X_{132}	$a_{132} = 1.69$
			3	28	X_{133}	$a_{133} = 1.41$
14	1.66	4	1	39	X_{141}	$a_{141} = 0.65$
			2	33	X_{142}	$a_{142} = 0.55$
			3	28	X_{143}	$a_{143} = 0.46$

Table 6. Satisfaction score for each steel pipe supplier received from supplying each pipe part no.

Part no. j	Percentage of monthly usage	Part maker	Steel Sheet Supplier p	Percentage of satisfaction	Decision variable	Satisfaction score (b_{jp})
1	8.30	2	1	23	Y_{11}	b_{11} = 1.93
			2	24	Y_{12}	b_{12} = 1.97
			3	17	Y_{13}	b_{13} = 1.40
			4	16	Y_{14}	b_{14} = 1.29
			5	20	Y_{15}	b_{15} = 1.70
2	2.30	9	1	21	Y_{21}	b_{21} = 0.48
			2	24	Y_{22}	b_{22} = 0.55
			3	20	Y_{23}	b_{23} = 0.46
			4	19	Y_{24}	b_{24} = 0.44
			5	16	Y_{25}	b_{25} = 0.37
3	3.83	6	1	26	Y_{31}	b_{31} = 0.99
			2	26	Y_{32}	b_{32} = 1.01
			3	17	Y_{33}	b_{33} = 0.64
			4	15	Y_{34}	b_{34} = 0.56
			5	17	Y_{35}	b_{35} = 0.64
4	2.29	2	1	23	Y_{41}	b_{41} = 0.53
			2	24	Y_{42}	b_{42} =0.54
			3	17	Y_{43}	b_{43} = 0.39
			4	16	Y_{44}	b_{44} = 0.36
			5	20	Y_{45}	b_{45} = 0.47

Table 7. Steel sheet supplier selection result.

Sheet part number	Steel sheet supplier selection result from	
	Current Decision	Proposed Model
1	sheet supplier no.3	sheet supplier no.2
2	sheet supplier no.3	sheet supplier no.2
3	sheet supplier no.2	sheet supplier no.2
4	sheet supplier no.2	sheet supplier no.1
5	sheet supplier no.2	sheet supplier no.1
6	sheet supplier no.3	sheet supplier no.1
7	sheet supplier no.2	sheet supplier no.3
8	sheet supplier no.1	sheet supplier no.1
9	sheet supplier no.2	sheet supplier no.1
10	sheet supplier no.3	sheet supplier no.1
11	sheet supplier no.2	sheet supplier no.1
12	sheet supplier no.2	sheet supplier no.2
13	sheet supplier no.2	sheet supplier no.2
14	sheet supplier no.2	sheet supplier no.2

Table 8. Steel pipe supplier selection result.

Pipe part number	Steel pipe supplier selection result from	
	Current Decision	Proposed Model
1	pipe supplier no.2	pipe supplier no.2
2	pipe supplier no.5	pipe supplier no.3
3	pipe supplier no.4	pipe supplier no.1
4	pipe supplier no.3	pipe supplier no.5

Table 9. Comparison of satisfaction scores from current decision and proposed model for each car seat model.

Car seat model	Satisfaction score from current decision	Satisfaction score from the proposed model	Percentage increase
1	30.15	37.86	25.57
2	26.43	28.85	9.15
3	27.58	30.31	9.91
4	26.31	27.92	6.12
5	26.91	26.94	0.14
6	29.72	30.85	3.81
7	28.89	34.28	18.65

5. Conclusion

In this paper, a mathematical model for evaluating second-tier suppliers of a case-study car seat manufacturer is developed by applying Analytic Hierarchy Process (AHP) and integer programming. This model helps the case-study company to obtain its suppliers' insight about how its suppliers (part makers) assess their suppliers (raw material suppliers). As the problem description, objective and constraints of this case-study company are different compared to those in the literature, there is a necessity of model development proposed in this paper for this particular problem. The results from the first part of this study show that the most important criterion is cost which is about 41%. Quality, Delivery, Service, and Risk factors are 24%, 14%, 12% and 9%, respectively.

In the second part of this research, an integer programming model is developed for supplier selection that considers the weight of each criterion obtained from the first part of this research. This model's objective is to maximize overall satisfaction for the part makers of the case-study manufacturer. After applying the proposed model to a car seat model produced by the case-study company, it is found the overall satisfaction can be increased from 30.15 (the company's current decision) to 37.86 (the proposed model), which is about 26% increase from the current decision. The management team of the case-study company also approves to apply our model to other car seat models and the result shows that our proposed model can improve the overall satisfaction of the case-study company's part makers for every car seat model.

For future research, it is interesting to extend our proposed model to other automotive parts with complex supply chain. In that case, it is necessary to obtain new evaluation criteria which are important for the part makers. Also, different constraints have to be considered to match requirements between material suppliers and part makers.

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