A Supplier Evaluation System for Automotive Industry According To Iso/Ts 16949 Requirements

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ABSTRACT

ISO/TS 16949 technical specification combines demands of all automotive manufacturers and indicates a well-defined, unique quality assurance system target for all companies in automotive industry. This study improves a special supplier selection and evaluation system for the companies in automotive industry due to the necessities of ISO/TS 16949.A hierarchical frame is first created by Voting Analytic Hierarchy Process (VAHP) to define the criteria and sub criteria of a quality assurance system. VAHP is improved by integrating Quality Function Deployment (QFD) when assigning weights of each criterion and sub criteria of the system. Linear programming model is used to convert the voting results to weights.

Keywords-Analytic hierarchy process, ISO/TS 16949, Quality function deployment, Supplier selection, Voting analytic hierarchy process

I. INTRODUCTION

ISO/TS 16949 is a technical specification prepared by the International Automotive Task Force (IATF) and Japan Automobile Manufacturers Association, Inc. (JAMA) with support from ISO/TC 176, quality management and quality assurance. ISO/TS 16949 technical specification is one of the most leading topics of automotive industry quality assurance system. This technical specification combines demands of all automotive manufacturers and indicates a well-defined, unique quality assurancesystem target for all companies in automotive industry. ISO/TS 16949 technical specification includes terms about necessity and importance evaluating suppliers regularly due to specification’s needs. This is more critical for companies whichcollaborate with many suppliers. Supplier selection and evaluation system should also include technical specification’s musts.

There are many studies which found place in literature about supplier selection and evaluation systems. However, there is lack of supplier evaluation systems for automotive industry including ISO/TS 16949 requirements.

This study improves a special supplier selection and evaluation system for the companies in automotive industry due to the necessities of ISO/TS 16949. In the study quality assurance system necessities are expressed in a hierarchical structure as criteria and sub-criteria. A hierarchical frame is first created by Voting Analytic Hierarchy Process (VAHP) to define the criteria and sub-criteria. However, in a quality assurance system there are more complex relationships. Voting Analytic Hierarchy Process (VAHP) is improved by integrating Quality Function Deployment (QFD) approach when assigning weights of each criterion and sub-criteria of the system. Two QFD structures are created to represent matrice relationships between hierarchy layers.

At the next step linear programming is used to convert the voting results to weights. The formulization is developed for the situation of having linear partial information. On the next step, minimum and maximum effect bounds of sub- criteria is calculated. The output of the mathematical programming of QFD matrice is used as an input of the mathematical programming. As last step, the average effects of criteria and sub-criteria are normalised. The last weights will be used in supplier selection and evaluation system directly. The point scale for the system is selected as [1-10] to let a flexible evaluation of each sub criteria. Then, suppliers are classified in four groups in this study.

II. LITERATURE REVIEW

There are many studies which found place in literature about supplier selection and evaluation systems. Some indicated methods in those studies are suitable to be used for both supplier selection and evaluation and some of them are suitable to be used for only selection or evaluation.

Akinc [1] improved a supplier selection method which minimizes annual material cost and quantity of suppliers while maximizing the number of suppliers with a high performance of delivery and quality. Roodhooft and Konings [2] improved a supplier selection and evaluation system by an activity based costing approach. System allows calculating the total cost caused by a defined supplier in the production process of an enterprise. Li et al. [3], improved a fuzzy method to compensate blindness of people when decision making for suppliers. Boer et al. [4] advised ELECTRE I to be used for eliminating best candidates from a big supplier candidate group and ELECTRE III for ranking those selected high performance candidate suppliers. Liu et al. [5], uses the data envelopment analysis (DEA) to select best suppliers for a defined product which is a classical multi-criteria decision making problem. Talluri and Sarkis [6] suggest a new multi criteria evaluation model which uses many performance criteria for supplier performance evaluation. Chen and Yang[7] indicated a method to integrate supplier and manufacturer capabilities under scope of "increasing profitability" which is improved from decreasing cost of purchased materials. Dulmin and Mininno [8], applied a new "multi criteria decision making" method to a middle size transportation enterprise in Italy by taking continuous changing of performance criteria, financial importance and multi-purpose structure of supplier selection decision into account. Chan [9] defined five new performance indicators as addition to classical cost and quality performance criteria which are commonly used in literature: source usage, flexibility, transparency, trust and innovation. Analytic Hierarchy Process (AHP) is used as multi variable decision making method. Wang et al. [10], improved a preventive goal programming based multi criteria decision making system which integrates AHP by considering both qualitative and quantitative factors. Pi and Low [11] calculated the quality loss which is caused by a unique supplier by using Taguchi lost function by using quality, delivery on time, cost and service criteria. Lasch and Janker [12] made a research in 193 enterprises about current supplier scoring systems and proved that current systems cannot fully meet practical needs. They proposed an alternative multi criteria decision making system which compares the ideal supplier with all suppliers and introduces a ranking and classifying result. Hong et. al. [13] improved mathematical programming model which can considerate changes of supply capabilities, suppliers and customer expectations in a defined time interval. Chen et al. [14] suggested a fuzzy decision making approach for complex decision of supplier selection. The method is suitable to use when performance variables cannot be defined numerically and foreknowledge and subjective forecasts exist. Kumar et al. [15] improved a "fuzzy multi-purpose integer programming" system for supplier selection problem with three main goals: cost minimization, quality maximization and just in time delivery. Ordoobadi [16] described a decision model that applies fuzzy arithmetic operators to manipulate and quantify decision maker's subjective assessments. Aksoy and Öztürk [17] presented, neural network (NN) based supplier selection and performance evaluation system in JIT production environment.

III. PROPOSED APPROACH

In this study, quality assurance system necessities are expressed in a hierarchical structure as criteria and sub-criteria. A hierarchical frame is first created by VAHP to define the criteria and sub-criteria and QFD is used to analyse matrice relations between criteria and sub-criteria, then, to convert the voting results to weights, linear programming model is used. The details of those steps explained in following sections.

3.1 Criteria and sub criteria of supplier selection and evaluation system

There are several criteria related to supplier selection process described in the literature. In this research, six criteria are determined by considering the effects to the general quality assurance system performance of a company. The criteria are shown below:

- Quality performance,
- Cost/cost management performance,
- Delivery performance,
- Management performance,
- Continuous development performance
- Supplier's relationship performance (indicates relations between supplier and it's sub supplier)

These criteria don't include enough details to assess a quality assurance system and sub criteria are created for each criterion as shown below.
Sub-criteria of quality performance are:

- SC 1.1. Advanced product quality planning should be applied in case of new product
- SC 1.2. Quality tracking of products and processes should be effective.
- SC 1.3. Statistical Process Control (SPC) should be applied and included in control plan.
- SC 1.4. Product inspection and control activities should be done effectively.
- SC 1.5. Inspection and production tools should be calibrated.
- SC 1.6. Defect prevention and solution techniques should be applied effectively.
- SC 1.7. Quality targets should be defined. Quality performance data should be recorded and controlled.
- SC 1.8. Internal audits should be done in the company in order to control conformance to ISO/TS 16949 needs.

- SC 1.9. Quality policy should be defined by top management and should be suitable to continuously improvement principle. Quality management system should be documented.

Sub criteria of cost/cost management performance are:

- SC 2.1. Financial management system should be effective. Short and long term financial planning should be done.
- SC 2.2. Cost management system should be effective. Cost of low quality should be measured.
- SC 2.3. Product planning system should be based on demand; and it should be suitable to reach production information at basic steps of process.
- SC 2.4. Inventory planning and control system should be effective and based on MRP.

Sub criteria of delivery performance are:

- SC 3.1. Delivery performance should be measured by an indicator and results should satisfy customer requirements.
- SC 3.2. Capacity should be managed to meet customer demand.
- SC 3.3. Batch quantities, packaging and labeling activities should be suitable to customer expectations. Products should be protected from delivery to customer.
- SC 3.4. Storage activities should be effective.

Sub criteria of management performance are:

- SC 4.1. Relationship in the company should be efficient.
- SC 4.2. Organization chart of the people effecting product quality should be defined.
- SC 4.3. A business plan suitable to company targets should be done and documented for short and long term.
- SC 4.4.Top management review meetings should be done on planned periodic intervals.
- SC 4.5. All employees should be trained about their job, safety, quality system. Employees who affect quality directly should have training on the job.
- SC 4.6. Company should meet the requirements of environment, health and safety.
- SC 4.7. Infrastructure and all inputs should be enough to meet product conditions. A proactive maintenance policy should be planned for tools.
- SC 4.8. Layout should be organized to help meeting quality needs, to have an effective usage of areas and easy material transportation.
- SC 4.9. Company should obey confidence principles in case of any need.

Sub criteria of continuous development performance are:

- SC 5.1. All activities supporting continuous development should be effective and positive results should be obtained.
- SC 5.2. Customer satisfaction should be the first target of the company. An efficient relationship is needed to use the voice of the customer as a guide in the company.
- SC 5.3. A process based quality management system should be implemented.

Sub criteria of supplier relationship performance are:

- SC 6.1. Supplier selection system should be defined and applied.
- SC 6.2. Supplier evaluation system should be defined and applied; relevant data should be collected.

The final hierarchical structure of criteria and sub criteria is shown in Fig. 1.

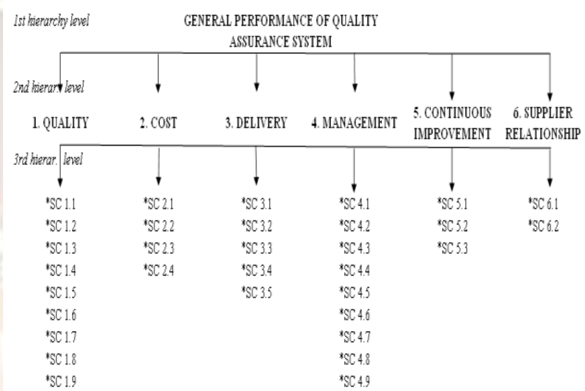

Figure 1. Hierarchical structure of criteria and sub criteria

3.2 Methodology of assigning weights of criteria and sub criteria

AHP is developed by Saaty to assist in multi-criteria decision-making problems. This method basically uses pairwise comparisons in decision making. VAHP is selected as the base of selection and evaluation system application. VAHP is an improved version of AHP. The reasons to prefer VAHP to AHP is summarised below:

1. VAHP is a more efficient system for group works. AHP needs all team members of the study to be at the same place on work time. It is not possible for all participants to be on the highest concentration level during the study. Moreover some participants can remain passive to declare their ideas. VAHP lets each participant to declare their ideas separately on the time that they prefer.
2. AHP uses a scale during pairwise comparison. The scale directly affects the efficiency of comparison results and causes a risk.
3. Applying VAHP is easier than AHP and takes less time.
4. AHP uses pairwise comparison for assessment criteria and also for the candidates. Comparing each pair of candidate suppliers causes a big

workload. Moreover, when a company uses AHP to select or rank suppliers, it has to refresh the same study when a new supplier is added to vendor list. This proves that using AHP to select supplier doesn't allow creating a supplier database. However having a supplier database is very critical especially for the companies which have large number of suppliers. By using VAHP method, a new supplier can easily be assessed by the system and the results can be added to database.

5. AHP is suitable to select the best suppliers through candidates, however is not suitable to assess a unique supplier.

VAHP uses the voters' idea when ranking criteria or subcriteria. *n*voters rank separately the criteria on the same hierarchy level. For example each voter ranks the criteria at the first hierarchy level: quality, cost, delivery, management, continuous improvement, supplier relationship. Then, each voter ranks the sub criteria at the second hierarchy level which belong to the same criteria. For example, SC 1.1-1.9 belongs to quality criteria and these nine sub criteria are ranked by each voter. SC 2.1-2.4 belongs to cost criteria and these four sub criteria are ranked by each voter. At the last step, VAHP uses Noguchi's [18] total ranking method to assign weights to each criterion and subcriteria due to the votes of *n* voters.

However, in real life, quality assurance system includes more complex relationships. In Fig 1, each sub criteria belongs to the criteria which effects more, but, also, sub-criteria are not completely independent from other criteria. For example, SC 6.1. effects supplier relationship criteria directly, and the effect is high. However, SC 6.1 may have effect on quality, cost, delivery, management or continuous improvement criteria. SC 6.1.'s effect to other criteria may be smaller but they are also important. To assess this complex relationship quality function deployment (QFD) approach is used. Han et al. [19] developed a linear programming model to assess matrix relationships between hierarchy levels and to assign weights to each criterion and sub criteria due to vote of *n* voters.

Two QFD structures are created to represent matrice relationships between hierarchy levels. Table 1 shows the matrice structure including sub criteria's effects to criteria. Table 2 shows the matrice structure including criteria's effects to general quality assurance system performance.

In QFD matrices, *x*, *y*, *z*, [ ] show the degree of relations. *x* represents very strong relationship, *y* represents strong relationship, *z* represents weak relationship and [] represents no relationship in case. In a methodical voting application, this evaluation is done by 15 ISO/TS 16949 auditors separately and the most voted degree is selected as the result of a cell. For example, if %60 of the 15 voters selected *x* for the effect of SC 1.1. to quality, the result of the voting for this cell is selected as *x*.

Table 1. Relationship matrice between criteria and sub criteria

Criterias \ Sub Criterias	SC 1.1.	SC 1.2.	SC 1.3.	SC 1.4.	SC 1.5.	SC 1.6.	SC 1.7.	SC 1.8.	SC 1.9.	SC 2.1.	SC 2.2.	SC 2.3.	SC 2.4.	SC 3.1.	SC 3.2.	SC 3.3.
1. QUALITY PERFORMANCE	x	x	x	x	x	x	x	x	x	y	x	x	y	x	y	y
2. COST/COST MANAGEMENT PERF.	y	x	x	x	x	x	x	y	y	x	x	y	x	x	x	y
3. DELIVERY PERFORMANCE	y	x	x	y	x	x	x	y	y	x	y	x	x	x	x	x
4. MANAGEMENT PERFORMANCE	y	y	x	y		x	x	x	x	x	x	x	x	y	x	y
5. CONTINUOUS IMPROVEMENT PERF.	y	x	x	y	y	x	x	x	x	y	x	x	x	y	y	x
6. SUPPLIER RELATIONSHIP PERF.	x	x	y	y	x	y	y	y	y	x	y	x	x	y	y	y

Criterias \ Sub Criterias	SC 3.4.	SC 3.5.	SC 4.1.	SC 4.2.	SC 4.3.	SC 4.4.	SC 4.5.	SC 4.6.	SC 4.7.	SC 4.8.	SC 4.9.	SC 5.1.	SC 5.2.	SC 5.3.	SC 6.1.	SC 6.2.
1. QUALITY PERFORMANCE	x	y	x	x	x	x	x	y	x	x	x	x	x	x	x	x
2. COST/COST MANAGEMENT PERF.	y	x	y	y	x	x	x	x	x	x	x	x	x	x	x	x
3. DELIVERY PERFORMANCE	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
4. MANAGEMENT PERFORMANCE	y	y	x	x	x	x	x	x	x	x	x	x	x	x	y	x
5. CONTINUOUS IMPROVEMENT PERF.	y	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
6. SUPPLIER RELATIONSHIP PERF.	y	y	x	x	y	x	x	x	x	x	x	x	x	y	x	x

Table 2. Relationship matrice between criteria and general quality assurance system performance

Criterias \ General Performance of Quality Assurance System	1.1. QUALITY PERFORMANCE	2. COST/COST MANAGEMENT PERF.	3. DELIVERY PERFORMANCE	4. MANAGEMENT PERFORMANCE	5. CONTINUOUS IMPROVEMENT PERF.	6. SUB SUPPLIER RELATIONSHIP PERF.
GENERAL PERFORMANCE	x	x	x	x	x	y

In this study, the linear programming model to convert the voting results to weights, introduced by Han et al. [19] is used. The formulization is developed for the situation of having linear partial information. The reason for this linear partial information acceptance is possibility of decision making under time pressure or lack of data, difficulty in expression ideas by numbers or by some kind of degrees, complex and uncertain environment and lack of concentration. In a QFD matrice, when customer attributes (CA) are on the rows and when the engineering characteristics (EC) are on the columns, notation of the linear programming model is shown below:

c_i	customer attribute
e_i	engineering characteristics
l	hierarchy levels of CA's $\{0,1,\ldots,L\}$
$L+1$	level of the hierarchy tree
m_l	number of CA at lth level
Y_j^l	the set of child nodes of jth attribute at the lth level
Y_j^0	the set of customer attributes at lowest level ($Y^0 = Y_j^0$)
d_i^l	importance rating of ith attribute at lth level ($d_i^0 = d_i$)
r_{ij}	effect of the jth engineering characteristic to lowest level ith customer attributes
we_j	weight of each engineering characteristic

$\theta_{min}(ec_j)$	minimum absolute bound of ec_j
$\theta_{max}(ec_j)$	maximum absolute bound of ec_j

*R*represents the constraints due to partial information of voters aboutr_{ij}. *R*set can be divided into $R_i$sets for each c_i(i=1,2,…,m_0). $R_i$set is composed of ER_ipartial information sets from voters or deciders and$\sum_{j=1}^{n} r_{ij} = 1$. So that two sets can be defined as$R=i=1m0Ri$ and $R_i = ER_i\{\sum_{j=1}^{n} r_{ij} = 1\}$ (Han et al., 2004). Constraint sets can be defined to represent partial information of c_is. $\gamma(d_i^l)$ (l=1,2,..,L) is the partial information set from voters or deciders for $d_i\gamma(d_3^2)$is partial information set of voters or deciders for d_3^2 inY_3^2. Also for all c_is on level l (l=1,2,..,L), a constraint is$\sum_{i\in Y_i^l}^{n} d_i^{l-1} = d_j^l$. For all c_is on level l(l=1,2,..,L), $\varphi = \{\sum_{i\in Y_i^l}^{n} d_i^{l-1} = d_j^l\}$set is defined. This equation shows that sum of the value of child nodes are equal to the value of parent node. Then, $\sum_{i=1}^{m_0} d_i^0 = 1$ is defined for customer attributes' constraints and the sum of the value of customer attributes on lowest level is 1. These three constraints set for c_is are defined by set $H = \gamma(d_i^l) \cup \varphi \cup \{\sum_{i=1}^{m_0} d_i^0 = 1\}$. Linear programming model set is defined as below:

$$\theta_{min}(ec_j) = min\sum_{i=1}^{m_0} d_i\, \delta^-(ec_j) (1)$$

s.t.

$$d_i^l \in H (2)$$

$$d_i^l \geq 0,\ i = 1,2,\ldots,m,\ l = 0,1,2,\ldots,L (3)$$

and

$$\delta^-(ec_j) = min r_{ij} \quad (4)$$

s.t.

$$r_{ij} \in R_i\ (5)$$

$$r_{ij} \geq 0\ (6)$$

In this linear programming set, first the value of $\delta^-(ec_j)$will be derived for all c_i($i \in Y^0$) by solving the second linear programming model and then $\theta_{min}(ec_j)$ will be minimized by putting the derived value of $\delta^-(ec_j)$ in the objective function. By solving the second linear programming problem, minimum value of all r_{ij} is calculated; by solving the same linear programming model after putting max to the objective function maximum value of all r_{ij} is calculated. At the second stage the first linear programming model is solved by putting minimum at the objective function to calculate the minimum effect bound of ec_j and the same programming model is solved by putting maximum at the objective function to calculate the maximum effect bound ofec_j. When minimum effect of ec_j is calculated minimum value of r_{ij}s are put in the model and when minimum effect of ec_j is calculated maximum value of r_{ij}s are put in the model.

3.3 Assigning weights of criteria and sub criteria

In supplier selection and evaluation system problem, sub criteria are in the place of e_i s and criteria are in the place of c_j s for the QFD matrice in Table 1and, for the QFD matrice in Table 2. criteria are in the place of e_is and general performance of quality assurance system is in the place ofc_j. Mathematical model is solved first for the QFD in Table 2, and then for the QFD in Table 1. In partial information case relationship between *x*, *y*, *z* voting of deciders can be defined as 1.5y≤x≤3y, 1.5z≤y≤3z and 3z≤x≤6z. Table 3 (a, b) presents the results of the mathematical programming model calculating min/max r_{ij} values of QFD matrice in Table 1.

Table 3(a). The value interval of r_{ij}s of matrice in Table 1

		SC 1.1.	SC 1.2.	SC 1.3.	SC 1.4.	SC 1.5.	SC 1.6.	SC 1.7.	SC 1.8.	SC 1.9.	SC 2.1.	SC 2.2.	SC 2.3.	SC 2.4.	SC 3.1.	SC 3.2.	SC 3.3.
1. QUALITY PERF.	min	0,034	0,034	0,034	0,034	0,034	0,034	0,034	0,034	0,034	0,012	0,034	0,034	0,012	0,034	0,012	0,012
	max	0,037	0,037	0,037	0,037	0,037	0,037	0,037	0,037	0,037	0,023	0,037	0,037	0,023	0,037	0,023	0,023
2. COST/COST MAN. PERF.	min	0,013	0,035	0,035	0,035	0,035	0,035	0,035	0,013	0,013	0,035	0,035	0,013	0,035	0,035	0,035	0,013
	max	0,024	0,040	0,040	0,040	0,040	0,040	0,040	0,024	0,024	0,040	0,040	0,024	0,040	0,040	0,040	0,024
3. DELIVERY PERF.	min	0,014	0,037	0,005	0,014	0,005	0,037	0,037	0,014	0,014	0,005	0,014	0,037	0,037	0,037	0,037	0,037
	max	0,026	0,043	0,016	0,026	0,016	0,043	0,043	0,026	0,026	0,016	0,026	0,043	0,043	0,043	0,043	0,043
4. MANAGEMENT PERF.	min	0,013	0,013	0,004	0,013	0,000	0,036	0,036	0,036	0,036	0,036	0,036	0,036	0,036	0,013	0,036	0,013
	max	0,024	0,024	0,016	0,024	0,000	0,040	0,040	0,040	0,040	0,040	0,040	0,040	0,040	0,024	0,040	0,024
5. CONTINUOUS IMP. PERF.	min	0,013	0,034	0,034	0,013	0,013	0,034	0,034	0,034	0,034	0,013	0,034	0,034	0,034	0,013	0,013	0,034
	max	0,023	0,038	0,038	0,023	0,023	0,038	0,038	0,038	0,038	0,023	0,038	0,038	0,038	0,023	0,023	0,038
6. SUPPLIER REL. PERF.	min	0,042	0,042	0,019	0,019	0,006	0,019	0,019	0,019	0,019	0,006	0,019	0,042	0,042	0,019	0,019	0,019
	max	0,058	0,058	0,029	0,029	0,185	0,029	0,029	0,029	0,029	0,185	0,029	0,058	0,058	0,029	0,029	0,029

Table 3(b). The value interval of r_{ij}s of matrice in Table 1

		SC 3.4.	SC 3.5.	SC 4.1.	SC 4.2.	SC 4.3.	SC 4.4.	SC 4.5.	SC 4.6.	SC 4.7.	SC 4.8.	SC 4.9.	SC 5.1.	SC 5.2.	SC 5.3.	SC 6.1.	SC 6.2.
1. QUALITY PERF.	min	0,034	0,012	0,034	0,034	0,034	0,034	0,034	0,012	0,034	0,034	0,004	0,034	0,034	0,034	0,034	0,034
	max	0,037	0,023	0,037	0,037	0,037	0,037	0,037	0,023	0,037	0,037	0,015	0,037	0,037	0,037	0,037	0,037
2. COST/COST MAN. PERF.	min	0,013	0,035	0,013	0,013	0,035	0,035	0,035	0,004	0,035	0,035	0,004	0,035	0,035	0,035	0,035	0,035
	max	0,024	0,040	0,024	0,024	0,040	0,040	0,040	0,016	0,040	0,040	0,016	0,040	0,040	0,040	0,040	0,040
3. DELIVERY PERF.	min	0,037	0,037	0,037	0,005	0,037	0,037	0,037	0,005	0,037	0,037	0,005	0,037	0,037	0,037	0,037	0,037
	max	0,043	0,043	0,043	0,016	0,043	0,043	0,043	0,016	0,043	0,043	0,016	0,043	0,043	0,043	0,043	0,043
4. MANAGEMENT PERF.	min	0,013	0,013	0,036	0,036	0,036	0,036	0,036	0,036	0,036	0,036	0,036	0,036	0,036	0,036	0,013	0,036
	max	0,024	0,024	0,040	0,040	0,040	0,040	0,040	0,040	0,040	0,040	0,040	0,040	0,040	0,040	0,024	0,040
5. CONTINUOUS IMP. PERF.	min	0,013	0,034	0,034	0,034	0,034	0,034	0,034	0,034	0,034	0,034	0,013	0,034	0,034	0,034	0,034	0,034
	max	0,023	0,038	0,038	0,038	0,038	0,038	0,038	0,038	0,038	0,038	0,023	0,038	0,038	0,038	0,038	0,038
6. SUPPLIER REL. PERF.	min	0,019	0,019	0,042	0,042	0,019	0,042	0,006	0,006	0,006	0,006	0,042	0,042	0,042	0,019	0,042	0,042
	max	0,029	0,029	0,058	0,058	0,029	0,058	0,185	0,185	0,185	0,185	0,058	0,058	0,058	0,029	0,058	0,058

Next step includes the calculation of minimum and maximum effects bounds of sub criteria. The *x*, *y*, *z* effects of criteria to general quality assurance system performance is used as d_i in the mathematical model. This means that when a criterion has a higher effect to general performance, its importance rating d_i is higher. When having partial information *x*, *y*, *z* relationship in Table 2 can be stated as:

$$1.5d_6 \leq d_1 \leq 3d_6 \text{ and } d_1 = d_2 = d_3 = d_4 = d_5$$

Table 4(a, b) shows the minimum-maximum effect bounds and average effects of all sub criteria.

Table 4 (a). Effect bounds of sub criteria to all criteria

	SC 1.1.	SC 1.2.	SC 1.3.	SC 1.4.	SC 1.5.	SC 1.6.	SC 1.7.	SC 1.8.	SC 1.9.	SC 2.1.	SC 2.2.	SC 2.3.	SC 2.4.	SC 3.1.	SC 3.2.	SC 3.3.
min effect bound	0.04	0.03	0.022	0.021	0.016	0.033	0.033	0.025	0.025	0.019	0.029	0.032	0.032	0.026	0.026	0.022
max effect bound	0.03	0.039	0.029	0.03	0.042	0.039	0.039	0.033	0.033	0.047	0.036	0.039	0.039	0.033	0.034	0.03
average effect	0.035	0.034	0.026	0.026	0.029	0.036	0.036	0.029	0.029	0.033	0.033	0.035	0.035	0.029	0.03	0.026

Table 4 (b). Effect bounds of sub criteria to all criteria

	SC 3.4.	SC 3.5.	SC 4.1.	SC 4.2.	SC 4.3.	SC 4.4.	SC 4.5.	SC 4.6.	SC 4.7.	SC 4.8.	SC 4.9.	SC 5.1.	SC 5.2.	SC 5.3.	SC 6.1.	SC 6.2.
min effect bound	0.022	0.026	0.032	0.025	0.033	0.036	0.032	0.017	0.032	0.032	0.014	0.036	0.036	0.033	0.031	0.036
max effect bound	0.03	0.033	0.039	0.034	0.039	0.042	0.057	0.045	0.057	0.057	0.026	0.042	0.042	0.039	0.039	0.042
average effect	0.026	0.029	0.035	0.03	0.036	0.039	0.044	0.031	0.044	0.044	0.02	0.039	0.039	0.036	0.035	0.039

As a last step, the average effects of criteria and subcriteria are normalised via equation (7):

$$r_j' = \frac{r_j}{\sum_j r_j} \text{and} \sum_j r_j' = 1 (7)$$

Table 5 (a, b) and Table 6 show the average effects of all criteria and subcriteria after normalisation.

Table 5 (a). Average normalised effects of sub criteria

	SC 1.1.	SC 1.2.	SC 1.3.	SC 1.4.	SC 1.5.	SC 1.6.	SC 1.7.	SC 1.8.	SC 1.9.	SC 2.1.	SC 2.2.	SC 2.3.	SC 2.4.	SC 3.1.	SC 3.2.	SC 3.3.
average normalised effect	0.033	0.032	0.024	0.024	0.027	0.034	0.034	0.027	0.027	0.031	0.030	0.033	0.033	0.027	0.028	0.024

Table 5 (b). Average normalised effects of sub criteria

	SC 3.4.	SC 3.5.	SC 4.1.	SC 4.2.	SC 4.3.	SC 4.4.	SC 4.5.	SC 4.6.	SC 4.7.	SC 4.8.	SC 4.9.	SC 5.1.	SC 5.2.	SC 5.3.	SC 6.1.	SC 6.2.
average normalised effect	0.024	0.028	0.033	0.028	0.034	0.036	0.041	0.029	0.041	0.041	0.019	0.036	0.036	0.034	0.033	0.036

Table 6. Average normalised effects of criteria

	1. QUALITY PERF.	2. COST/COST MAN. PERF.	3. DELIVERY PERF.	4. MANAGEMENT PERF.	5. CONTINUOUS IMP. PERF.	6. SUPPLIER REL. PERF.
average normalised	0.182	0.182	0.182	0.182	0.182	0.091

3.4 Design of supplier selection and evaluation system

By applying AHP, the final weight of each sub criteria is calculated by multiplying the weight of the sub criteria and the criteria that it belongs in hierarchical level. Final weights of sub criteria are shown in Fig.2.

Final weights seen in Fig 2 will be used in supplier selection and evaluation system directly. The point scale for the system is selected as [1-10] to let a flexible evaluation of each sub criteria. This means that an auditor will rate each sub criteria between 1 and 10; and multiply each rate of the sub criteria with the weight of related sub criteria in Fig.2. Suppliers are classified in four groups according to their scores in this system.

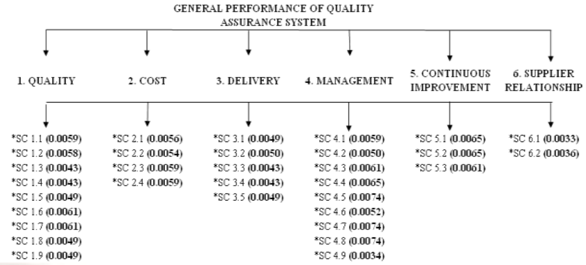

Figure 2. Final weights of sub criteria

- **Class_A supplier:** System definitely advices to work with this class.
- **Class_B supplier:** A System advice to work with this class, but, an action plan is demanded from supplier to reach Class_A level after 6 months.
- **Class_C supplier:** System doesn't advice to work with this class. An action plan is demanded from supplier to reach Class_B after 3 months. If the supplier is successful to reach Class_B, it's evaluated again due to rules of Class_B suppliers.
- **Class_D supplier:** System definitely doesn't advice to work with this class. Action plan is not demanded.

In the proposed system maximum score that a supplier may have is 1.75531 and the minimum score is 0.17553. So the score intervals of the classes are defined as below:

- **Class_A supplier:** [1.36037-1.75531]
- **Class_B supplier:** [0.96542-1.36036]
- **Class_C supplier:** [0.57048-0.96541]
- **Class_D supplier:** [0.17553-0.57047]

IV. CONCLUSION

ISO/TS 16949 technical specification is one of the most leading topics of automotive industry quality assurance system. This specification combines separate demands of automotive manufacturer companies in Europe and America and presents a unique quality assurance standard to all companies in automotive industry.

ISO/TS 16949 technical specification includes terms about necessity and importance evaluating suppliers regularly due to specification's needs. Quality assurance system's efficiency is directly linked to the quality assurance system of suppliers. This is more critical for companies which collaborate with many suppliers. Supplier selection system should also include technical specification's musts. This study proposes a systematic approach for automotive industry to evaluate current suppliers and select new suppliers due to ISO/TS 16949 requirements. The proposed system can also be used in a company to assess their own quality assurance system. Proposed system is very simple to use and ready to apply in industry. It doesn't need neither a special training about the evaluation system nor ISO/TS 16949 for application.

In this study quality assurance system necessities are expressed in a hierarchical structure as criteria and sub criteria. This is important to let an auditor to focus on details of a quality assurance system. VAHP methodology is improved to assess matrice relationships of quality assurance system hierarchy and QFD discipline is used to assess the relationships between criteria and sub criteria. QFD let to realize the effect of a sub criteria to all criteria, not only to criteria that it belongs at the hierarchy. At the next step linear programming is used to convert the voting results to weights. Suppliers are classified in four groups in this system. The proposed system can also recommend to decision makers in automotive industry for each supplier class when evaluate current suppliers and select new suppliers due to ISO/TS 16949 requirements.

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