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A methodological proposal to define supplier development programs

Una propuesta metodológica para definir programas de desarrollo de proveedores

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Abstract

One of the Concerns of Multinational Companies (MNC) when they decide to produce in low-cost countries is to have a reliable domestic supplier base that guarantees a continuous flow of high-quality products from the region of production to the consumption markets. MNC may elect to strength its supplier base by a) asking current international suppliers to open facilities in a new sourcing region or b) investing in supplier's development programs. The objective of this work was to propose a methodology to identify those suppliers with the highest opportunity to attain acceptable levels of competitiveness and then define the contents of the more suitable development program. The selection of potential suppliers is based on the key criteria and indicators used in the automotive industrial sector in Mexico and with the support of the quantitative techniques of Fuzzy Analytical Hierarchical Process (FAHP) and Multidimensional Scaling (MDS). After a root-cause analysis, a series of development activities are defined for each supplier and those that will lead to the largest improvement given time and cost restrictions are selected through Goal Programming. The applicability of the proposed methodology is demonstrated for the case of the automotive sector, one of the most important sectors for the Mexican economy.
Keywords: supplier development, competitiveness, international sourcing, Fuzzy AHP, MDS, Goal Programing.

Resumen

Una de las preocupaciones de las Empresas Multinacionales (MN) cuando deciden producir en países de bajo costo es el contar con una base confiable de proveedores locales que les garantice un flujo continuo de productos de calidad desde la región de producción hasta los mercados de consumo. Las MN pueden elegir fortalecer su base de proveedores ya sea mediante: a) solicitar a sus actuales proveedores internacionales que se localicen en la zona de nuevo abasto elegida o b) invertir en programas de desarrollo de proveedores. El objetivo de este trabajo es proponer una metodología para identificar aquellos proveedores con la mejor oportunidad de alcanzar niveles de competitividad aceptables y luego definir el contenido del programa de desarrollo más apropiado. La selección de los proveedores potenciales se basa en indicadores críticos e indicadores empleados por el sector automotriz de México, apoyada por la aplicación de las técnicas cuantitativas del Proceso de Jerarquización Analítico Difuso (FAHP) y Escalamiento Multidimensional (MDS). Después de un análisis de causas-raíz, se define una serie de actividades de desarrollo para cada proveedor potencial y aquellas que resulten con la mayor mejora posible, dadas las restricciones de tiempo y costo, se eligen a través de la Programación por Metas (GP). La aplicabilidad de la metodología propuesta se demuestra para el caso del sector automotriz, uno de los más importantes para la economía mexicana.
Descriptores: desarrollo de proveedores, competitividad, abasto internacional, AHP Difuso, MDS y Programación por metas.

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Introduction

One of the problems faced by *Multinational Companies* (MNC) when they decide to produce in Mexico is to find qualified regional suppliers able to provide strategic items. This problem is partly due to the difficulties of defining valid criteria for evaluation and selection of suppliers, and of satisfying them with the current capabilities (MacCarthy and Atthirawong, 2003; Kinkel and Maloca, 2009).

An effective *Supplier's Development* (SD) program requires among other things a diagnosis of the performance of current and new potential suppliers in order to identify those capabilities in need of improvement to guarantee a proper level of competitiveness. The objective of this work was to define a methodology to identify the weaknesses and strengths of a supplier in comparison with other suppliers within the same industrial sector in order to design a customized development program validated by the purchaser.

The methodology developed in this work has the following advantages:

1) It guarantees that the supplier's development programs are aligned with the current process of evaluation used by lead MNCs of the automotive sector, one of the strategic sectors in Mexico, and
2) It ensures that every supplier would receive the proper training and assistance during its development.

Theoretical background

A major concern of lead companies in the automotive sector is to minimize the risk of disruptions of the supply chain due to the high percentage of components in the final products that are provided by external suppliers (Krause and Ellram 1997a; Watts and Hahn, 1993). Therefore, a reliable base of local suppliers becomes a critical requirement when selecting a sourcing region.

If a *Buying Firm* (BF) does not have a reliable base of suppliers or does not have the capacity or the interest of manufacturing them, the alternatives are to transfer its current foreign supplier base to the new manufacturing location or to develop existing suppliers (Krause and Ellram 1997b; Krause *et al.*, 2000). The first alternative reduces the chances of domestic suppliers to participate in global supply chains resulting in negative long-term effects on the regional industrial and economic development. In an effort to correct this situation, the federal government and some state governments in Mexico have supported programs for the development of domestic suppliers (Arroyo *et al.*, 2012). How to select suppliers for development and what activities/resources are required to improve their capabilities are relevant questions that call for objective and valid techniques to assess the current level of suppliers' competitiveness and define suitable contents for the development programs.

Even when SD was initially perceived as a set of activities aimed to improve supplier's performance with expected short-term results, currently it is recognized as a long-term approach to improve the capabilities of the supplier (Watts and Hahn, 1993). However, from the perspective of the BF, SD must attain both objectives, firstly it must improve supplier performance in critical criteria such as cost, quality and delivery, and secondly it must place the supplier into a systematic process of continuous improvement (Krause *et al.*, 1997b). Under this perspective, SD can be defined as: "Any effort of a buying firm working with its supplier(s) to increase its performance and/or capabilities and meet the buying firm's short and/or long-term supply needs. Moreover, SD promotes on-going improvements that are intended to benefit both buyer and supplier(s)" (Ahmed and Hendry, 2012). From a strategic perspective, the development of suppliers should be a continuous activity because performance criteria evolve according with the market's demands (Hartley and Choi, 1996). However, there are criteria such as quality, delivery, cost, technology or cycle time that are permanently used (Krause *et al.,* 2000).

SD activities may be of two types: "indirect" or "reactive" –with little or no involvement of the BF oriented to overcome specific performance deficiencies of supplier- and "direct" or "strategic" –with high involvement of the BF aimed to improve the long-term supplier capabilities (Krause *et al.*, 1998; Wagner, 2006). During the SD program definition, the BF needs to decide what type of activities should be implemented based on the resources, time, current capabilities of suppliers and the analysis of the direct (reductions on the cost of products) and indirect (a more diversified supplier market) of the program (Krause *et al.*, 2007). But according to Ahmed and Hendry (2012), the literature on SD lacks of a specific framework that guides the selection of appropriate development activities that will produce the desired results, and the description of valid indicators to monitor and evaluate the impact of the SD program over time.

BFs address the problem of SD in different ways, however the general framework for the systematic definition of a SD program consists of the following steps (Hahn *et al.*, 1990):

1) Program authorization referring to the recognition by the top management of the need to design activities to raise the competitiveness of current suppliers.
2) Program organization comprising the integration of a team responsible of managing the SD.
3) Supplier evaluation which consists of assessing the performance of current or potential suppliers taking into account the requirements of the BF.
4) Definition of SD activities that involves the identification of specific causes of the unsatisfactory supplier's performance to use them as guidelines for the definition of topics and activities to include in the SD program.
5) Consensual development plans regarding the contents and time schedule of the SD program; the contribution of a group with expertise in SD is relevant to complete this step.
6) Implementation of the SD and evaluation of results.

The methodology proposed in this work is aimed to support steps 3, 4 and 5 by including the use of multicriteria techniques (Fuzzy AHP, MDS and Goal Programming).

Methodology approach

The proposed methodology comprises three phases and five stages that are depicted in Figure 1 and described in detail in the following paragraphs. The methodology was derived from a theoretical basis and empirically validated through its application in the automotive sector, critical to the Mexican economy due to their fast growth and contribution to the gross national product (GNP).

Phase 1. Definition of criteria and key indicators used in the supplier evaluation process

The results of this phase guarantee that the improvement in competitiveness will create value to buyers because any action is focused on the upgrading of critical evaluation criteria. This phase comprises two stages:

1) The definition of criteria and associated key indicators.
2) The assignment of weights of importance to each criteria.

The identification of criteria and sub-criteria is based on theoretical and empirical basis. Preliminary criteria are defined in terms of the existing literature, and then validated through a discussion with a panel of experts integrated by critical decision makers from the automotive sector. The phase is completed by the operationalization of each criteria through a meaningful set of tangible key indicators validated by the experts. For example the key indicators defined to measure the criterion "product and process quality" are: number of rejected parts, PPM (defective parts per million of parts produced), downtime hours, quality certifications obtained by the supplier, failure contention and traceability systems, quality control of incoming materials, and training and certification of suppliers.

After identifying key criteria and sub-criteria, the panel of experts is required to assign weights of importance to each one. The quantitative technique used to accomplish this task is *Fuzzy Analytical Hierarchy Process* (FAHP) which is an extension of the well-known AHP methodology that considers the vagueness of the

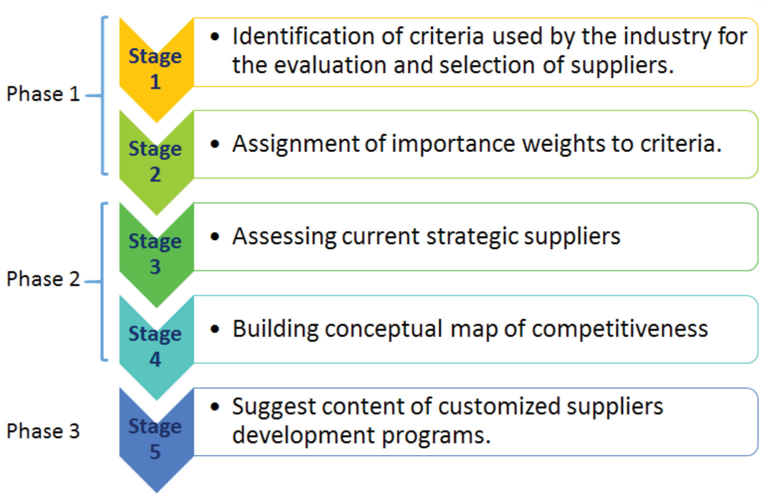

Figure 1. Phases and stages of the proposed methodology

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linguistic variable describing the importance of a criteria. It is assumed decision makers clearly understand the meanings or the importance of linguistic values but not everyone has the same perception of a particular description. For example, the term "definitely more important" may be equivalent to a noticeable difference in the mind of a DM but interpreted as a strong difference by another. FAHP captures this ambiguity by using fuzzy sets and membership function to assign quantitative rates to the DM pairwise comparisons between criteria at the same hierarchical level.

The consistency of the individual opinions is assessed before combining them to get a final set of weights for each criteria and sub-criteria in the evaluation hierarchy. Following FAHP, suppliers are evaluated on each criterion and the corresponding weights used to compute a compensatory global score of performance or competitiveness. But this score is too aggregated to allow the identification of suppliers with good chance for development, therefore we suggested the construction of maps of relative competitiveness.

Phase 2. Construction of a conceptual map of competitiveness for suppliers

The conceptual maps depict graphically the relative level of performance (competitiveness) of a group of suppliers. The input of the map are the supplier's evaluation performed by DM according to the criteria and sub-criteria defined in the previous phase. Each supplier is rated on a scale going from 0 to 10, where 0 means the lowest acceptable level in a key indicator and 10 represents the ideal level. The scores of all indicators belonging to a particular criteria are averaged and then weighted according with the relative importance of each criteria and sub-criteria. Finally each supplier is represented in a 2- or 3-dimensional map thanks to the use of *Multidimensional Scaling* (MDS) techniques.

The graphical output of MDS reflects the appreciation of decision makers regarding the relative competitive position of each supplier. In the map, the Euclidean distance between suppliers represents similarities (or dissimilarities) between them, and the distance with respect to the "ideal supplier" shows the "lack of competitiveness" of a particular supplier. Clusters or groups of suppliers with similar levels of competitiveness are easily identified. Suppliers in the same cluster have equivalent levels of global performance or competitiveness, meanwhile groups of suppliers with very different levels of performance are placed far away from each other on the map.

The visual representation of the complex set of relationship among suppliers is simplified by MDS. The underlying dimensions "explain" the similarity between suppliers. For example, two suppliers may be close (similar) because they have similar rates of performance in terms of hard criteria like quality, price and on-time delivery. Thus, the similarity between suppliers is a function of their similarity in scores across a particular subset of attributes representing "global key" or "substantive" indicators for decision makers. These global key attributes are a simplified aggregation of individual criteria that decision makers within an industrial sector ultimately use to distinguish one supplier from another.

It is important to realize that these substantive dimensions or simplified keys are expected to be considerably smaller than the number of criteria used to rate suppliers. This is because the performance criteria, while cognitively distinct, may be highly inter-correlated in the minds of experts (e.g. quality, on-time delivery and clear contingency plans jointly describe a dependable supplier or be associated with tangible results) and therefore contain some redundant information. Then the basic utility of the perceptual map is the identification of:

1) Groups of suppliers that may be developed with the same strategy (workshops, joint projects, periodic feedback, etc.).
2) Alternative providers of products and services.
3) Suppliers requiring the same effort to be developed.

Once suppliers judged suitable for development are identified, the particular contents of a SD program need to be specified during a last phase.

Phase 3. Outline a customized supplier development program that increases the competitiveness of a supplier and its opportunity of being part of the automotive supplier chain

Beginning with phase 3, an "acceptable" cut-off level of global performance was defined by the DM after using a nominal management technique during the workshop. Cooper (2007) recommends setting this lower bound as the average of all performance rates, but depending on the strategic importance of the product supplied, the number of suppliers and the resources available to implement the SD program, other bounds may be defined. In this proposal, the maximum performance level was defined in terms of the supplier with the best observed performance provided this supplier got a minimum "9" score on all first-level criteria, otherwise the maximum

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corresponded to the "ideal" supplier (a score of 10 on all criteria). The normalized supplier's performance ratings were used to compute inefficiency gaps. By following the Pareto principle, those criteria that account for roughly 80% of the total weights of importance were analyzed during the following phase to define proper activities for development.

The areas where the supplier achieve a performance level equal to or greater than the acceptable cut-off level were judged "satisfactorily efficient" and may not require immediate support while those areas where the supplier's performance gaps are the largest should be subject to a problem's root causes analysis (Weber *et al.*, 1998). This means experts need to identify the causes of underperformance by checking on the specific indicators and suggest a set of customized development activities. The time and resources required to attain an acceptable level of performance was estimated from the opinions of DMs and academics from a major Mexican university with large experience in training programs and improvement projects involving companies in the automotive sector.

Finally, specific activities were assigned to suppliers by applying a third quantitative technique, *Goal Programming* (GP). This technique was selected because it helps to solve problems with multiple goals or objectives (sometimes in conflict) when is not possible to find a solution that optimizes all objectives. We assumed there are restrictions in time and budget to any development program because of the limited resources available to complete the project. Therefore, the problem was defined as what activities assign to each supplier to get the maximum improvement in performance for all participant suppliers given the restrictions on resources. The main idea of GP is to transform the multiple criteria of performance (price, quality, accuracy of delivery, etc.) on a single goal (global competitiveness) and get an efficient solution to this problem even though it is not optimal with respect to all the objectives. This implies maximizing the global efficiency of the suppliers' base by selecting those projects that minimize the performance gaps in the different areas -and consequently increase the global competitiveness - while considering the limited available budget and the specific time frame of the SD project.

The results of applying the described methodology are discussed in the next section.

Analysis and discussion of results

Phase 1

The hierarchical structure representing the criteria used to evaluate and select suppliers in the automotive sector was defined through a literature review and a workshop with experts from lead firms in this sector -Gates Rubber, Parker Fluid Connectors, ZF Lemforder, Robert Bosch, Trelleborg, Gestamp, Mahle de México, Maccsa-.

Figure 2 shows the resulting hierarchy. The degree of importance of each criteria and sub-criteria was computed with Fuzzy AHP. Table 1 and Figure 3 show the global weights of importance for the first level criteria. The most important criteria were in total agreement with the literature review and include: purchase price, product & process quality and reliability of delivery. Interestingly, criteria like "risk management" had one of the lowest weights while criteria such as "greenness" were not included in the hierarchy. In the case of "risk management", the low importance was attributed to the fact current suppliers have capacity in excess and are located nearby the BF, therefore no interruptions of supplies are expected. Green criteria on the other hand are not currently used because existing environmental regulations are relatively easy to fulfill.

General scores of supplier's performance can be computed at this phase to rank suppliers but they are insufficient to define meaningful SD activities and visualize the effort required to improve current performance on the defined criteria. Phases 2 and 3 are intended to overcome these difficulties.

Phase 2

Following the proposed methodology, the next step was to build a perceptual map to picture suppliers according to their levels of competitiveness. The perceptual maps constructed by applying MDS (Figure 4) graphically describe how competitive are nine of the strategic suppliers of the automotive sector while Table 2 shows the coordinates of each supplier in the map along with the distance to the ideal supplier.

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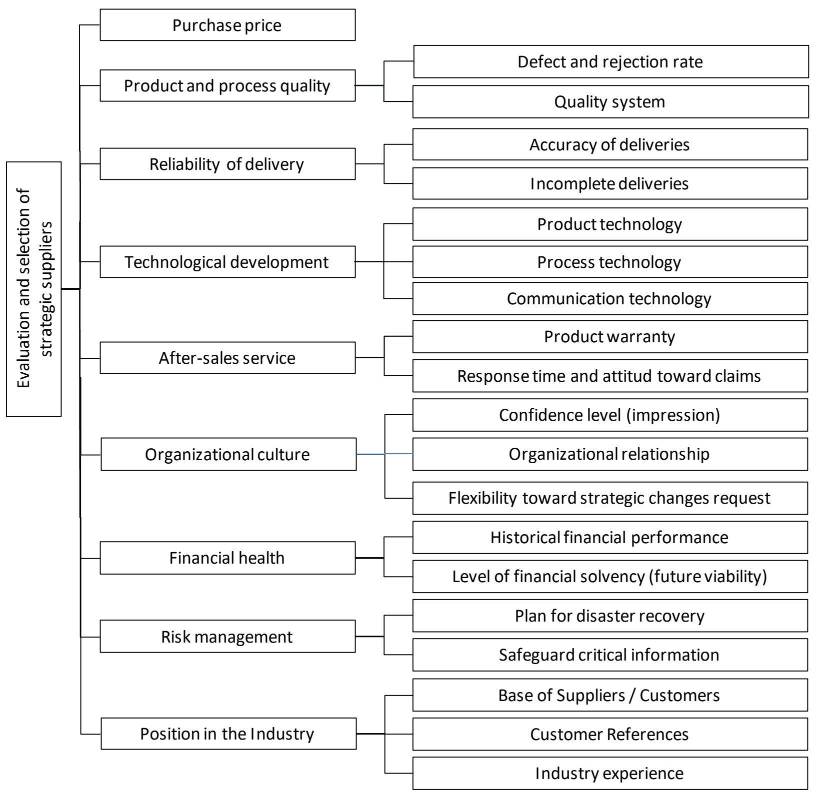

Figure 2. Hierarchical structure of the criteria used in the supplier evaluation process

Table 1. Global weights of first level criteria

Evaluation criteria	Assigned weight
Purchase price	0.2154
Product and process quality	0.1871
Reliability of delivery	0.1616
Organizational culture	0.1275
After-sales service	0.1113
Financial health	0.0884
Position in the industry	0.0514
Technological development	0.0500
Risk management	0.0075

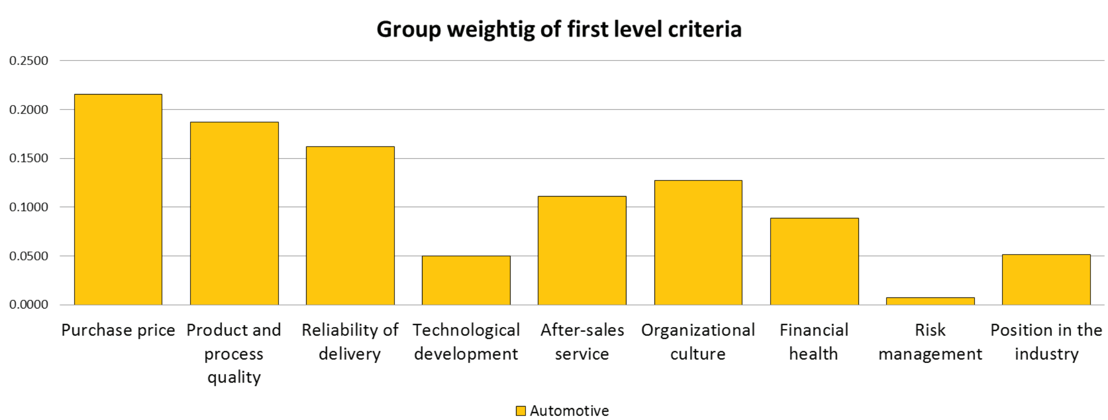

Figure 3. Global weights of first level criteria

Based on the map, different approaches may be applied to perform the identification of viable candidates for development; benchmarking current suppliers versus world-class suppliers and performing a Pareto analysis are two recommendable choices (Krause *et al.*, 1998; Hahn *et al.*, 1990). Under the benchmark approach used by American auto companies, suppliers are classified into four ordered classes. Suppliers with a world-class performance are assigned to the high-level class; these suppliers do not require more development efforts than feedback and incentives. In the second class there are suppliers with small shortages on only few core criteria. Therefore these suppliers have the potential to achieve the required performance levels and are the most viable candidates for development. Suppliers with important performance deficits on several core criteria are assigned to the third-class; these suppliers need to reduce their performance gaps before they are judged viable candidates for development. Finally, the suppliers in the lowest class have limited capacity or exhibit significant deficiencies in multiple criteria, then they are scheduled for elimination (Hahn *et al.*, 1990).

Following the benchmark approach, concentric circles around the "ideal supplier" were drawn in the MDS map in order to identify the most competitive suppliers. At least one supplier is included in each circle and all equidistant suppliers (Euclidean distance) to the "ideal supplier" have the same level of global competitiveness even when their performance on specific criteria could be different.

At Figure 4 and Table 2 we can observe that supplier 3 has the highest level of competitiveness (0.930) because is the closest to "ideal supplier"; in contrast supplier 4 is the least competitive (0.649). Groups or clusters of suppliers with similar level of competitiveness are suppliers {7, 9} and suppliers {1, 2, 6}. Results are used to decide which group of suppliers includes the more suitable candidates for development. BF may establish a minimum level of competitiveness to admit suppliers in a SD program. For example assume suppliers with a level of competitiveness greater than 0.850 are judged highly competitive to improve their performance by themselves; suppliers with a level of competitiveness between 0.700 and 0.850 are suitable candidates for de-

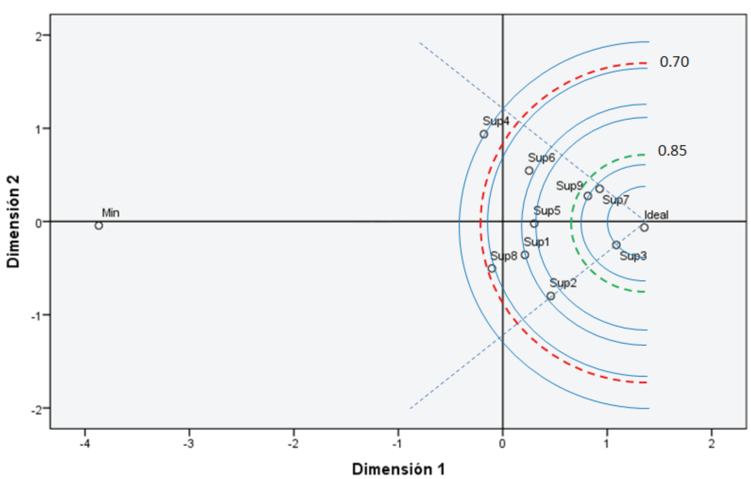

Figure 4. Map of Euclidean distances between suppliers automotive sector

Table 2. Euclidean distances to the ideal suppliers and level of competitiveness of suppliers of the automotive sector

Supplier	Horizontal coordinate	Vertical coordinate	Distance to ideal	Global level of competitiveness
S1	0.2115	–0.3574	1.1806	0.774
S2	0.4594	–0.7989	1.1586	0.778
S3	1.0871	–0.2509	0.3267	0.937
S4	–0.1809	0.9372	1.8335	0.649
S5	0.3004	–0.0223	1.0555	0.798
S6	0.2524	0.5454	1.2599	0.759
S7	0.9275	0.3505	0.5955	0.886
S8	–0.1043	–0.5032	1.5241	0.708
S9	0.8141	0.2745	0.6382	0.878
Ideal	1.3551	–0.0640	0.0000	1.000

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velopment while suppliers with a level of competitiveness below 0.700 require too much investment to be developed. Then suppliers 3, 7 and 9 will only receive feedback and incentives, suppliers {1, 2, 5, 6, 8, 9} would be considered viable SD candidates while suppliers {4} are not considered for development and can be discarded from the supplier base unless the capacity of the other suppliers is insufficient to fulfill BF demand.

In case new suppliers are available or the initially discarded ones improve their performance to the acceptable levels, they would be included in the perceptual map to determine if they are viable candidates for development.

Phase 3

This last phase defines the areas to be developed on each supplier based on the analysis of the reasons that explain their positions on the map. In order to show how it works we take the case of the suppliers 1 and 2.

According to the previous results, these suppliers have very similar levels of global competitiveness (0.774, 0.778) but not so far from the ideal, therefore they are eligible for development. The areas of improvement correspond to the largest gap with respect to the ideal performance, to help experts to visualize the situation, differential gaps were represented in Figure 5. The dashed line in the graph corresponds to the lowest acceptable level of performance (efficiency in-

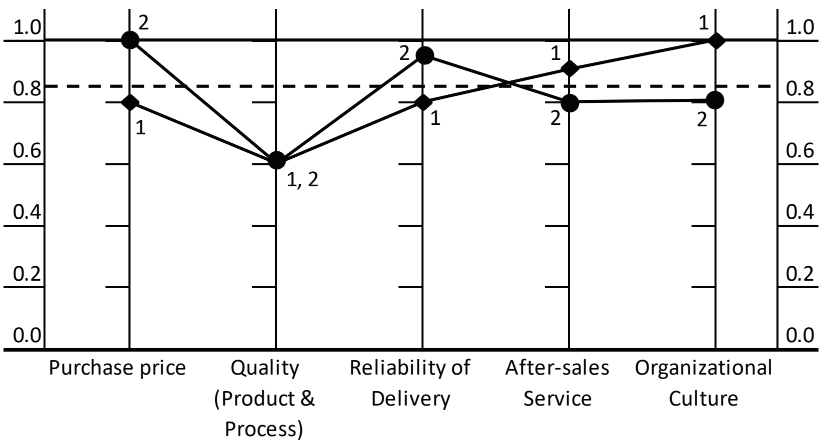

Figure 5. Normalized performance levels of suppliers 1 and 2 in the most important criteria

Table 3. Key indicators used to evaluate supplier's performance by criterion

Criteria	Key indicator
Purchase price	Product price Product development costs Planned cost reductions Total landed costs
Product & process quality	Nnumber of rejected parts PPM (defective parts per million of parts produced) Downtime hours Quality certifications obtain by supplier Failure contention and traceability systems Incoming material controls Operators training and certification
Reliability of delivery	Number of lots delivered out of time Number of lots with less quantity of parts Number of lots with mixed parts Number of lots without certifications
After-sales service	Communications channels Quality of service Time of response
Organizational Culture	Confidence level Organizational relations Commitment to strategic changes (win-win)

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dex of 0.85). The areas or criteria where the supplier achieve an efficiency index equal to or greater than this bound are considered "satisfactorily efficient" and do not require improvement while areas where supplier has an efficiency index below this level must be considered eligible for root cause analysis and posterior development. Following the steps suggested by Hahn *et al.* (1990) regarding the design of a SD program, a panel of experts identified the "root causes" of underperformance of key indicators of each criteria (Table 3) and suggest appropriate and customized development activities (projects).

The areas to be taken into account in the root causes analysis are the following:

Table 4. Performance gains expected for development projects (activities)

Supplier 1	Current performance gap (b_{ij})	0.200	0.400	0.200		
Area of improvement	Project description	Purchasing price	Quality of product & process	Reliability of delivery	Duration (months)	Cost (1000 USD)
1	Reduction in energy and indirect material consumption	0.010	-	-	2	10
1	Development of alternative materials	0.080	-	-	4	15
1	Reduction of production scrap	0.010	-	-	3	35
2	Certification of raw materials and control	-	0.050	-	2	5
2	Improvement of the welding process	-	0.100	-	3	45
2	Certification of operators	-	0.050	-	2	10
2	Implementation and certification in quality tools (APQP, FMEA, MSA, PPAP and SPC)	-	0.050	-	1	20
2	Traceability improvement and failure contention systems	-	0.020	-	1	30
2	Implementation of Poka Yoka systems (mistake proofing)	-	0.030	-	2	10
3	Electronic shipping certification		-	0.050	2	30
3	Inventory management and inventory reduction		-	0.100	3	35
Total expected improvement, duration and cost of development		**0.100**	**0.300**	**0.150**	**25**	**245**

Supplier 2	Current performance gap (b_{ij})	0.400	0.200	0.200		
Area of improvement	Project description	Quality of product & process	After-sales service	Organizational culture	Duration (months)	Cost (1000 USD)
1	Implementation and certification in quality tools (APQP, FMEA, MSA, PPAP and SPC)	0.050	-	-	1	20
1	ISO and TS 16949 Certification	0.200	-	-	6	55
1	Implementation of layered process audit system	0.050	-	-	2	10
2	Improvement of the system of failure reports and assistance	-	0.060	-	2	15
2	Improvement of the system of product exchange and replacement	-	0.050	-	3	32
2	Improvement of technical support	-	0.040	-	2	10
3	Preparation of multi-task workers (job rotation)		-	0.060	3	35
3	Empowerment system		-	0.070	2	20
3	Implementation of collaborative functional teams		-	0.020	3	15
Total expected improvement, duration and cost of development		**0.300**	**0.150**	**0.150**	**24**	**212**

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Supplier 1: Purchase price, product and process quality and reliability of delivery.

Supplier 2: Product and process quality, after-sales service and organizational culture.

SD projects for each of the areas where a supplier did not reach an acceptable level of performance were defined in terms of the practical knowledge of the group of selected experts. The time and cost of implementation of each project as well as the expected improvements in performance were estimated by the panel of experts and are shown in Table 4. The total time of implementation is computed by assuming projects or activities are implemented sequentially because there is a restricted scheduled budget.

Usually there are restrictions on time and budget to be spent in development programs. In this case, priority activities were chosen through the solution of a GP model. The decision variables x_{ijk} are the activities to be implemented in order to achieve the largest improvement in performance. The sub-indexes identify the supplier (i), the area or criteria requiring improvement (j) and the number of projects or activities defined for this area (k). Each project takes a time to be completed (t_{ijk}), involves a cost (c_{ijk}) and results in an improvement in performance (a_{ijk}).

The aim is to maximize the efficiency of suppliers by selecting those projects that minimize the performance gaps in the different areas (b_{ij}) and consequently increase the global competitiveness of suppliers while considering that the buyer has a limited available budget (*M*) and needs to develop the supplier during a specific time frame (*T*).

The linear programming formulation is as follows

Minimize

$$z = \sum_{j=1}^{n} \sum_{i=1}^{m} w_j d_{ij}$$

Subject to

$$\sum_{k=1}^{r} a_{ijk} x_{ijk} + d_{ij} = b_{ij}$$

$$\sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{r} t_{ijk} x_{ijk} \le T$$

$$\sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{r} c_{ijk} x_{ijk} \le M$$

For i = 1, ..., m   j = 1, ..., n   k = 1, ..., r

$$x_{ijk} \begin{cases} 0 \\ 1 \end{cases}$$

where

d_{ij} = Performance deviation of supplier *i* in the area *j*
w_j = Degree of importance of the (criterion) area *j*

The development activities assigned to each supplier after solving the GP problem given a maximum authorized budget of 100,000 USD to develop each supplier during a year (12 months) are shown in Table 5.

Once selected projects are implemented, the suppliers' performance is expected to change after a year. Figure 6 depicts the expected reductions on the performance gaps: the level of global competitiveness of supplier 1 would improve from 0.77 to 0.86 while the global competitiveness of supplier 2 would increase from 0.78 to 0.89. These new levels of competitiveness would allocate suppliers to the "satisfactory performance" class (above the lower bound of 0.85 defined in the previous stage).

Table 5. Supplier's development programs

Supplier 1
Development of alternative materials Row material certification and control Welding process improvement Operators certifications Quality core tools (APQP, FMEA, MSA, PPAP and SPC) certification
Supplier 2
Quality core tools (APQP, FMEA, MSA, PPAP and SPC) certification ISO/TS 16949 Certification Layered Process Audit System implementation Improve communication systems for failure reports/ attendance

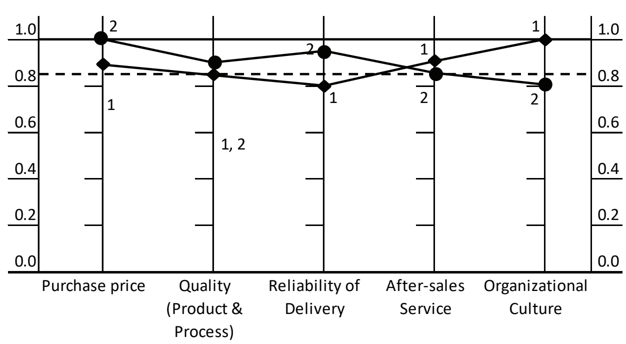

Figure 6. Expected performance gaps after development of suppliers

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Conclusions

The proposed methodology is based on well-grounded quantitative multi-criteria techniques that support decision makers of lead companies in the automotive sector to design an efficient supplier's development program. The application of Fuzzy AHP simplifies the task of defining and weighing key evaluation criteria for supplier's assessment. MDS facilitates the identification of suppliers with similar levels of competitiveness and viable for development, meanwhile the use of GP optimizes the assignment of development activities taking into account restrictions in resources (time and money). The results generated with each technique are of easy interpretation to the decision makers and simplify the consensus, the identification and selection of alternatives. The validation of this proposed methodology was done through its application in the case of defining SD activities for suppliers of the automotive sector. The results of this application overcome some of the subjectivity that exists in the definition of what is supplier's competitiveness and the selection of appropriate development activities that guarantee the expected results.

The application of the methodology ensures the contents of the SD program are suitable to each supplier because:

1) Development activities are based on the performance criteria critical to the industrial sector.
2) Viable suppliers are identified based on a benchmark approach.
3) SD activities are defined according to the relative deficiencies of each supplier.

Other industrial and service sectors could also follow the phases of the methodology just by defining the adequate criteria and corresponding key indicators relevant for the sector, and integrating a group of experts to collaborate with.

The proposed methodology may be also applied by governmental and educational institutions interested in the implementation of effective and efficient supplier development programs. Its application makes possible to define activities and allocate resources more efficiently than the current scheme of offering a generic training to suppliers (Rodríguez, 2012; Instituto Nacional del Emprendedor [INEM], 2015).

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