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Multicriteria methodology for decoupling point placement in manufacturing systems

Metodología multicriterio para la ubicación del punto de desacople en sistemas de manufactura

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Abstract

Synchronization between production scheduling and real demand is an issue of great concern for production practitioners and academics. Put in a nutshell, the solution requires the placement of a decoupling point in order to get a trade-off between efficiency and flexibility. In the context of a postponement production strategy, a decoupling point is an inventory buffer to create independence between the process and final demand. Upstream of the decoupling point, the process is managed under a make-to-stock approach; in contrast, downstream operations meet the final demand under a make-to-order approach. In this sense, the present paper proposes a multicriteria methodology to locate decoupling points in manufacturing systems. The methodology consists of two stages, with two and three steps respectively. In the first stage, the decision criteria and alternative for decoupling points are chosen. In the second one, the final decoupling point placement is determined. By applying the methodology in a metalworking company, the location of the decoupling points for nine production lines was obtained.

Palabras clave: decoupling point, manufacturing system, methodology, multicriteria, postponement.

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Resumen

La sincronización de la planeación de la producción y la demanda real es un tema de interés tanto para profesionales como para investigadores. Dicho en pocas palabras, la localización del punto de desacople es una solución que permite tener un equilibrio entre eficiencia y flexibilidad. En el contexto de una estrategia de aplazamiento; el punto de desacople es un inventario que crea independencia entre el proceso y la demanda final. Aguas arriba del punto de desacople se gestiona bajo un enfoque de producción continua; por el contrario, aguas abajo la operación hace frente a la demanda final mediante un enfoque de manufactura bajo pedido. En este sentido, este trabajo presenta una metodología multicriterio para localizar el punto de desacople en sistemas de manufactura. La metodología consiste en dos etapas, con dos y tres pasos, respectivamente. En la primera etapa, los criterios de decisión y los puntos de desacople alternativos son seleccionados. En la segunda, el punto de desacople final es localizado. La aplicación de la metodología se hizo en una empresa del sector metalmecánico para detectar los puntos de desacople para nueve líneas de producción.

Keywords: aplazamiento, metodología, multicriterio, punto de desacople, Sistema de Manufactura.

INTRODUCTION

Competition between industries keeps a progressive growth driven by technological developments and globalization; as a consequence, more aggressive strategies to increase the market share have emerged. In this context, cost reduction while improving service and costumer experience are some mandatory goals for companies [1]. Despite the fact that large-scale production has been a goal for several industries in order to reduce costs, today's market flexibility requirements make it difficult to achieve this objective [2]. Product flexibility means better manufacturing capacities in the production system, reflected in the ability to produce on a small scale to face highly volatile markets [3], [4].

The aforementioned problem has been the target of many researchers from the operations management perspective. In fact, two of the most important investigation topics are how to deal with uncertain demand [5] and how to integrate this uncertainty into the production system [6]. The state of the art offers some strategic alternatives, as postponement, to manage the trade-off among efficiency, flexibility and other competitive priorities [7], [8].

The postponement concept was introduced by Alderson [9]. It is defined as a mass customization strategy, aimed to give a better product experience and quality to customers, besides a wide portfolio under uncertainty conditions [10],[11]. The postponement approach can be applied on multiple fields [3]. From the logistic perspective, product development postponement, purchasing postponement, production postponement, assembly postponement, packaging postponement and logistic postponement are some typical categories of this study field [6], [12].

Production postponement is the target topic of the present paper. Put in a nutshell, the aim of this strategy is to delay the product final assembling and create a work-in-process inventory in order to face the market fluctuations at a lower cost [1], [3]. This production strategy allows increasing the customer penetration point in the production system [6] without affecting, in great manner, the cost reduction goals. The placement of this work-in-process inventory is called the Decoupling Point (DP).

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In this sense, DP is understood as a physical point where the production system must be divided into two different sub-systems [13]. Upstream of the DP, the aim is to achieve low cost by implementing a make-to-stock production planning approach. Conversely, downstream the production system is focused on flexibility by mean of a make-to-order production planning approach [14], [15]. The decision-making related to the DPs placement is a strategic issue that requires a careful analysis tailored to each particular production system[14], [16].

Although, there are several methods to address the DP placement in manufacturing systems, most of them are focused on quantitative methods that show some limitations in real contexts due to a set of variables involved in this strategic decision [17]. Some multicriteria techniques, such as AHP and ANP, have also been applied to locate the DP; however, a broad level of managers participation (experts) in the decision-making is not easily allowed [18].

Therefore, the present paper proposes a multicriteria methodology for the DP placement in manufacturing systems. The methodology consists of five steps; in which expert methods and weighting techniques are combined. As main contribution, this methodology allows the integration of quantitative and qualitative variables as well as the participation of decision-makers to establish the proper location of the DP. By applying the methodology in a real metalworking company, some relevant advantages and limitations are shown.

For its presentation, the article has been structured as follows: a brief literature review is presented in Section 2. The six-steps methodology is explained in section 3. By applying the methodology in a real case, the placement of the decoupling points for nine production lines were obtained in Section 4. Finally, in Section 5, some relevant conclusions are presented.

LITERATURE REVIEW

Specialized literature recognizes the importance of DP placement, but few methods to address it are available. Shidpour *et al.* [16] states that most of the studies related to DP are focused on conceptual issues and highlights a lack of practical solutions. However, a systematic literature review undertaken in the present paper identified 34 papers addressing this problem.

The identified solution methods were grouped into the following categories: effect-cause-effect analysis (ECE), decision-making expert system (ES), queuing theory (QT), Single objective optimization (OM), matrix geometric method (MG), multi-objective model (MM), simulation model (SM), analytic network process or fuzzy analytic network process (ANP), and multi-objective model with technological entropy (ME). According to each category, the reviewed papers were classified as shown in table 1.

Table 1. Solution methods for DP placement

Author	Model								
	ECE	ES	QT	OM	MG	MM	SM	ANP	ME
[13]						x			
[16]						x			
[19]							x		
[20]				x					
[21]							x		
[22]		x							
[23]							x		
[24]				x					
[25]				x					
[26]						x			
[27]								x	
[28]						x			
[29]						x			
[30]				x					
[31]									x
[32]								x	
[33]					x				
[34]				x					
[35]				x					
[36]				x					
[37]				x					

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Author	Model								
	ECE	ES	QT	OM	MG	MM	SM	ANP	ME
[38]				x					
[39]				x					
[40]				x					
[41]			x				x		
[42]			x	x					
[43]					x				
[44]			x		x				
[45]	x								
[46]					x				
[47]								x	
[48]							x		
[49]				x					
[50]				x					

As shown in table 1, OM seems to be the most popular solution method and a lack of applications in the rest of methods was identified. In particular, OM offers sophisticate solutions achieving optimal results based on quantitative variables. However, the complexity of systems prevents that these models can achieve more realistic solutions [51].

Regarding ECE, Ashayeri *et al.* [45] proposed a manufacturing system division (make to order and make to stock), in order to get a balance between capacity and flexibility. In turn, Wang [22] analyzed the complexity of DP placement when multiple customers with different needs are considered; to deal with this situation, an ES to weigh the decision parameters was proposed.

Other contributions Karrer et al. [41], Teimoury et al. [42] have applied queuing network models by incorporating a probabilistic demand function. Like the optimization models [30],[35], MG [43],[44] and MM [16],[52], these implies mathematic arranges to achieve optimal solutions. However, in complex real situations these kind of models have to apply heuristics and meta-heuristics solutions to face the computational complexity.

Herdenstierna *et al.* [21] highlight the importance of the DP placement problem; these authors state that beyond the use of statistical information, the incorporation of other solution methods to get a more realistic solution must be considered. In this way, they propose an SM, in order to analyze the dynamic of the process behavior in upstream and downstream operations.

Hemmati *et al.* [32] recognize the difficulties of the DP placement problem due to the great number of involved variables. Therefore, they propose an ANP solution in order to incorporate quantitative and qualitative factors affecting this decision. In addition, Rafiei *et al.* [27] and Rafiei *et al.* [47] integrated the fuzzy sets theory with ANP, aimed to decrease vagueness and ambiguity of experts judgments. Other multicriteria model proposed by Luo *et al.* [30] followed a different approach; their paper developed a multi-objective model to place a DP based on the so-called technological entropy function, considering three main variables: function realization degree, production cost and lead time.

Although there exist several contributions proposing solutions to solve the DP placement, based on a critical analysis of the literature, at least three gaps can be identified: first of all, in order to solve complex problems, quantitative methods (OM, QT, MM, MG and SM) have to address simplified situations in which some qualitative variables must be ignored [53]. On the other hand, when qualitative methods (ECE and ES) are applied, the results can be imprecise and too subjective [54]. To solve these shortcomings, multicriteria techniques seem to be a more appropriate way to support the DP placement due to the importance of integrating qualitative and quantitative criteria. Notwithstanding, some relevant techniques such as AHP, ANP and ME can be improved through a better involvement of experts in the decision making. In particular, when various experts must participate, a concordance test is necessary in order to check de degree of agreement among them.

METHODOLOGY

The proposed methodology provides a new alternative for DP placement in production systems. The structure takes into consideration the fundamentals of multicriteria techniques, expert methods and some contributions of Sarache *et al.* [55] applied in other kind of decision problems. Also, the scope and company needs must be considered in order to get a proper solu-

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tion according to the technical capabilities of the production system. Some topics typically involved in the decision-making could be: unpredictable demand, wide variety of products, products with similar characteristics and inventory cost, among others. A brief explanation of each step is as follows:

Step 1. Identification of alternatives for decoupling points (ADP)

The DP placement is a decision affected by many factors related to the production system particularities [56]. Therefore, at this step the methodology intends to identify the different alternatives of decoupling points (ADP) for each factor.

1.1 Factors selection. It is necessary to identify the factors affecting the ADP placement for each particular company. Thus, the ADP selection must be done according to the characteristics and company requirements. Some typical factors, such as product characteristics (design, materials), process configuration (operations sequence, critical operations and assembly operations) and requirements of the customers (customization) can be considered. A technical analysis of the production system can be useful at this step.

1.2 Experts selection for* ADP *identification. After identifying the decision factors for the ADP placement, it is necessary to choose a group of experts in order to assign the different ADP for each production system. An expert is an experienced decision maker able to give proper information about a particular issue [57], [58].

1.3* ADP *selection. Based on their knowledge and experience, the group of experts should establish a list of ADP for each production system under analysis. Some group work techniques can be used to support this activity.

Step 2. Criteria identification

A preliminary group of criteria can be defined from relevant contributions based on the state of art or previous experience of the company. However, a list of final criteria must be defined by contrasting the preliminary group with the company characteristics and requirements.

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Step 3. Weighting of criteria

Aimed to identify the relative importance among criteria and based on previous contributions of Sarache *et al.* [55], two weighting techniques are proposed. In the first one, the criteria prioritization through a simple weighting and the modified triangle of Fuller is obtained. In the second one, the two obtained weighting are combined to get a more accurate result. The particular sub-procedure is as follows:

3.1 Experts selection for criteria prioritization. At this step a new expert's selection process should be done. These experts have to evaluate the different criteria required to select the best ADP. Regarding the number of experts, they can range from 7 to 50 [59], [60].

3.2 Subjective weighting I (Simple weighting). Each expert should establish the relative importance among criteria. By using a scale from 1 to *n (n= number of criteria)*, each expert assigns *n* to the most important criterion and 1 to the less important. In that way, the higher the number, the greater is the importance of the criteria. By applying equation 1, the subjective weighting I per each criterion can be obtained.

$$W_{jA} = \frac{\sum_k C_{jk}}{\sum_j \sum_k C_{jk}} \quad (1)$$

Where

C_{jk}: Relative importance of criterion *j* given by the expert *k*.

W_{jA}: Subjective weighting I of criterion j.

3.3 Concordance testing. The Kendal index (W) is used for testing the level of agreement among experts. If W is equal or greater than 0.5, the weighting is validated. W can be calculated as follows [59], [61]:

Calculation of mean value of ranges (*T*):

$$T = \frac{M(n+1)}{2} \quad (2)$$

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Calculation of deviation for the criteria (D^2):

$$D^2 = \sum_{j=1}^{n} \left(\sum_{k=1}^{M} (C_{jk}) - T \right)^2 \qquad (3)$$

Calculation of Kendall's index (W):

$$W = \frac{12\, D^2}{M^2 (n^3 - n)} \qquad (4)$$

Where

n: Number of criteria.

M: Number of experts.

3.4 Subjective weighting II (the modified triangle of Fuller). To obtain this weigh, the modified triangle of Fuller is used [55]. By applying this method, a paired comparison among criteria is performed. A value of 1 is assigned to a criterion when the decision maker considers that it is more important than another; otherwise, a zero (0) must be assigned.

Table 2. Paired comparison among criteria given by expert k

Criteria	$Criteria_1$	$Criteria_2$	$Criteria_3$	...	$Criteria_n$
$Criteria_1$	1	P_{12k}	P_{13k}	...	P_{1nk}
$Criteria_2$	P'_{12k}	1	P_{23k}	...	P_{2nk}
$Criteria_3$	P'_{13k}	P'_{23k}	1	...	P_{3nk}
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
$Criteria_n$	P'_{1nk}	P'_{2nk}	P'_{3nk}	...	1

Where

P_{jik} : Preference of criterion j respect to criterion i, according to expert k.
P'_{jik} : Binary logical complement of P_{jik}.
[i,j] : Subscripts count for criteria $i,j = 1, 2, 3,..., n$

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$$0 \leq P_{jik} \leq 1$$

$$\text{If } P_{jik} = 0 \text{ then } P'_{jik} = 1$$

$$\text{If } P_{jik} = 1 \text{ then } P'_{jik} = 0$$

By applying equations 5 and 6, the total subjective weight II for each criterion must be obtained.

- Calculation of subjective weight II of criterion *j*, given by expert *k*:

$$W_{jBk} = \frac{\sum_i P_{jik}}{\sum_j \sum_i P_{jik}} \quad (5)$$

Where

W_{jBk}: subjective weight II of criterion *j*, given by expert *k*.

- Calculation of subjective weight II of criterion j:

$$W_{jB} = \frac{\sum_k W_{jBk}}{\sum_j \sum_k W_{jBk}} \quad (6)$$

Where

W_{jB}: Subjective weight II of criterion *j*.

3.5 Determination of final weight. To obtain the final weight of each criterion, the results of the previous two techniques are combined by applying equation 7 [55]:

$$W_{jD} = \frac{W_{jA} W_{jB}}{\sum_{j=1}^{n} (W_{jA} W_{jB})} \quad (7)$$

Where

W_{jD}: Final weight of criterion *j*.

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Step 4. Criteria evaluation

Typical criteria can be made up of qualitative or quantitative characteristics. Hence, the identification of the proper source to collect the relevant data for each ADP must be performed.

4.1 Identification of information sources for criteria evaluation. At this step, through an appropriate data collection process, the criteria characteristics must be identified. For quantitative data, information can be obtained from company statistical records, while for the qualitative ones, the experts involvement is proposed [18], [62].

4.2 Criterion evaluation. For quantitative data, information is collected from company statistics. For qualitative criteria, company managers (experts) perform the evaluation. These personnel should be properly informed of the process characteristics on which the ADP must be defined. In this case, experts will evaluate each alternative based on the scale proposed by Saaty [63] (see table 3). By applying an AHP model, the judgement of each expert is analyzed to obtain the hierarchy of each criterion (priority vector).

Table 3. Fundamental scale

Intensity of importance on an absolute scale	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance

Source: Saaty [63].

The comparison among alternatives is represented in a triangular matrix (table 4), where the intercession of the row *f* and the column *p* shows the comparison between *f* and *p* alternatives. It is necessary to keep in mind that comparison is made for the upper triangular matrix, since the lower is mathematically reciprocal.

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Table 4. Triangular matrix for criteria comparison

ADP	ADP_1	ADP_2	ADP_3	...	ADP_p
ADP_1	1	a_{12k}	a_{13k}	...	a_{1mk}
ADP_2	$1/a_{12k}$	1	a_{23k}	...	a_{2mk}
ADP_3	$1/a_{13k}$	$1/a_{23k}$	1	...	a_{3mk}
⋮	⋮	⋮	⋮	⋮	⋮
ADP_m	$1/a_{1mk}$	$1/a_{2mk}$	$1/a_{3mk}$	$1/a_{m\,m-1k}$	1
sum a_{pk}	a_{1k}	a_{2k}	a_{3k}	...	a_{mk}

Where

$$a_{pk} = \sum_{f} a_{pfK} \qquad (8)$$

m : Number of ADP's.

[p,f] : Subscripts count for ADP's; p, f = 1, 2, 3,…, m.

a_{pf} : Value of the paired comparison between ADP_p and ADP_f made by expert *k*.

A : Comparison matrix.

As shown in equation 9, the results must be normalized to obtain the relative weight for each cell:

$$n_{pfk} = \frac{a_{pfk}}{a_{pk}} \qquad (9)$$

Where

n_{pfk}: Normalized value of comparison between ADP_p respects to ADP_f made by expert *k*.

In equation 10, the priority vector (eigenvector) is the *S* vector with dimension *m*, formed by S_{fk} elements. The final weighting (ranking) of a particular ADP is obtained by applying equation 11.

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$$S_{fk} = \frac{\sum_p n_{pfk}}{m} \quad (10)$$

$$S_f = \frac{\sum_k S_{fk}}{\sum_f \sum_k S_{fk}} \quad (11)$$

4.2.1 Consistency testing. The consistency of the experts rating must be tested through the Random Consistence Index (RI). If RI is equal or lower than 0.1, the rating is accepted; otherwise, the process must be revised. The mathematical formulation is as follows [64].

- Based on the non-normalized matrix and the priority vector, a resulting vector (R) is obtained. This is made up of the relative weight for each ADP (Equation 12).

$$R = R_{n\,x\,1} = A_{n\,x\,n} \,.\, S_{n\,x\,1} = \quad (12)$$

- Largest or principal eigenvalue (d_{max}) is calculated by applying equation 13.

$$d_{max} = \frac{R}{nS} \quad (13)$$

- Consistency index calculation (CI):

$$CI = \frac{d_{max} - n}{n - 1} \quad (14)$$

- Consistency ratio calculation (CR):

$$CR = \frac{CI}{RI} \quad (15)$$

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Table 5. Random consistency index RI

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.89	1.11	1.24	1.32	1.40	1.45	1.49

Source: Saaty [63].

Step 5. ADP evaluation

In order to select the best DP among the ADP, each alternative must be evaluated for each criterion. After this process, the obtained results must be homogenized and standardized, such that the obtained information can be compared and analyzed.

5.1 Data collection and construction of the ADP ***and criteria matrix.*** As shown in Table 6, data collection is carried out through a matrix (criteria – alternative points) to record the value of each criterion for the different ADP.

Table 6. Matrix of ADP and criteria

Concept	$Criteria_1$	$Criteria_2$	...	$Criteria_n$
ADP_1	AC_{11}	AC_{12}	...	AC_{1n}
ADP_2	AC_{21}	AC_{22}	...	AC_{2n}
. . .	. . .	. . .	. . .	. . .
ADP_m	AC_{m1}	AC_{m2}	...	AC_{mn}

Where

AC_{pj}: Assessment of criterion *j* at ADP *p*

5.2 Data homogenization. This process is aimed to direct all assessments given to criteria toward the same decision approach. In other words, all criteria will be evaluated under the same perspective (minimizing or maximizing). So, when belongs to a vector oriented to an optimization perspective different to the methodology goal, it is necessary that each of this particular vector be transformed by applying the mathematical complement proposed in equation 16.

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$$AC'_{pj} = \frac{1}{AC_{pj}} \quad (16)$$

Where

AC'_{pj}: Homogenized value AC_{pj} of the vector AC_j

5.3 Data normalization. Normalization must be addressed for each. In this case, the total sum of all ADP_m for each criterion must be calculated. Then, each is expressed as a percentage of the obtained total sum (equation 17). As a result, the normalized matrix is obtained (see table 7).

$$AC^N_{pj} = \frac{AC_{pj}}{\sum_p AC_{pj}} \quad (17)$$

Where

AC^N_{pj}: Normalized value of AC_{pj}

Table 7. Normalized matrix

Concept	$Criteria_1$	$Criteria_2$	...	$Criteria_n$
ADP_1	AC^N_{11}	AC^N_{12}	...	AC^N_{1n}
ADP_2	AC^N_{21}	AC^N_{22}	...	AC^N_{2n}
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
ADP_m	AC^N_{m1}	AC^N_{m2}	...	AC^N_{mn}

Step 6. Decoupling point selection

The weighted sum for each alternative must be calculated as shown in equations 18. The outcome represents the final grade for each alternative, from which the best ADP must be chosen. If data were homogenized as a minimization vector, the lesser must be chosen; otherwise, the largest is chosen.

$$Q_p = \sum_j AC^N_{pj} W_{jD} \quad (18)$$

Where

Q_p : Final grade for the ADP$_p$.

CASE STUDY

Herragro S. A. is a metalworking company created in 1960 in Manizales City to produce hand tools by using steel hot forging process. Its main customers are agricultural, construction, mining and industrial companies [65]. Domestic market represents 70 % of the total sales and the rest is sold in 14 countries. In general, the product portfolio is made up of more than one thousand items. Due to the variety of markets, products and countries, obtaining an accurate sales forecast becomes in a difficult task. Also, the customer requirements for product customization claim for more flexibility in the production system.

As in many industrial sectors, competition from Asian manufacturers is becoming fierce, so the customization requirements should be harmonized with efficiency goals. Therefore, aimed to improve the production system flexibility, the proposed methodology was applied to locate the DP for nine production lines. The evaluated production lines were: mattocks, shovels, machetes, axes, blades, wheelbarrows, chisels, hoes and sledgehammers. The obtained results are shown as follows.

Step 1. Identification of alternatives for decoupling points (ADP)

1.1 Factors selection. According to the company requirements and based on contributions of Verdouw *et al.* [56] and Xu [66], the three selected criteria were: product characteristics, production system configuration and market requirements.

1.2 Experts selection for* ADP *identification. A group of four experts was selected. These experts were chosen based on their position and experience in the company (see table 8).

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Table 8. Selected experts for ADP identification

Factors	Role of the selected expert
Market demands	Chief Marketing Officer
Product characteristics	Quality Manager Engineering Manager.
Production system configuration	Production Manager.

1.3 ADP ***selection.*** As can be seen in table 9, an ADP for each factor was selected on each production line.

Table 9. ADP for each production line

Line	Factors	ADP
Line 1	Market demands	Polish
	Product characteristics	Heat treatment
	Production system configuration	Sharpen
Line 2	Market demands	Heat treatment
	Product characteristics	Paint and label
	Production system configuration	Heat treatment
Line 3	Market demands	Heat treatment
	Product characteristics	Heat treatment
	Production system configuration	Sharpen
Line 4	Market demands.	Heat treatment
	Product characteristics	Heat treatment
	Production system configuration	Polish
Line 5	Market demands	Heat treatment
	Product characteristics	Heat treatment
	Production system configuration	Sharpen
Line 6	Market demands	Punch and mark
	Product characteristics	Punch and mark
	Production system configuration	Clean
Line 7	Market demands	Sharpen
	Product characteristics	Weld
	Production system configuration	Sharpen

Line	Factors	ADP
Line 8	Market demands	Straighten
	Product characteristics	Thermal treating
	Production system configuration	Straighten
Line 9	Market demands	Heat Treatment
	Product characteristics	Heat Treatment
	Production system configuration	Heat Treatment

Step 2. Criteria identification

The selected criteria and a brief explanation are presented in table 10.

Table 10. Selected criteria

Criteria	Definition
Lead time (C_1)	Required time of an item to complete customization needs
Productivity (C_2)	Amount of products that can be produced in a shift, taking into account the allocated resources
Stock (C_3)	Unit cost per stored item on DP
Process characteristics (C_4)	Number of process that needs to be performed (downstream) to complete customization needs.
Customization costs (C_5)	It measures the added cost to obtain a customized product.
Storage (C_6)	It evaluates the ADP_m capability to offer proper conditions for work in process storage.
Risk of product damage (C_7)	It evaluates the ADP_m capability to the avoid product damages that affect the quality.
Easiness to restart the production process (C_8)	It evaluates the ADP_m capability to facilitate the process restart without incur in reworking operations.

Step 3. Weighting of criteria

3.1 Experts selection for criteria prioritization. Seven people considered the most experienced of the company were selected. The chosen roles were: engineering manager (E_1), quality manager (E_2), production manager (E_3), logistics manager (E_4), production supervisor (E_5), quality engineer (E_6) and maintenance manager (E_7).

3.2 Subjective weighting I (Simple weighting). By applying equation 1, the obtained results are summarized in table 11.

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Table 11. Subjective weighting I

Criteria	Rating assigned by the experts (C_{ik})								W_{ja}
	E_1	E_2	E_3	E_4	E_5	E_6	E_7	$\sum_k C_{jk}$	
C_1	5	6	7	7	7	8	7	47	0.19
C_2	6	5	8	6	6	6	8	45	0.18
C_3	7	7	3	8	5	7	4	41	0.16
C_4	4	4	2	3	2.5	3	1	19.5	0.08
C_5	1	3	5	5	4	5	5	28	0.11
C_6	2	2	1	1	1	1	2	10	0.04
C_7	8	8	4	4	8	4	8	44	0.17
C_8	3	1	6	2	2.5	2	3	19.5	0.08

3.3 Concordance testing. For this case study 7 experts (*M*) and 8 criteria (*n*) were considered. Based on equations 2 and 3 the obtained values for *T* and D^2 were 31.5 and 1431.5 respectively. In consequence, the Kendall concordance index was 0.696 (equation 4).

3.4 Subjective weighting II (the modified triangle of Fuller). As an example, table 12 shows a paired comparison given to the selected criteria by expert 4 (E_4).

Table 12. Paired comparison given by expert 4

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	Total Sum E_4
C_1	1	0	0	1	1	1	0	1	5
C_2	1	1	1	1	1	1	0	1	7
C_3	1	0	1	1	1	1	0	1	6
C_4	0	0	0	1	1	1	0	1	4
C_5	0	0	0	0	1	0	0	0	1
C_6	0	0	0	0	1	1	0	1	3
C_7	1	1	1	1	1	1	1	1	8
C_8	0	0	0	0	1	0	0	1	2

The same procedure is repeated for the rest of experts. In table 13 the subjective weighting II (W_{jB}) given by the group of experts is exhibited.

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Table 13. Subjective weighing II

Criteria	Rating assigned by the expert (W_{jBk})							W_{jB}
	E_1	E_2	E_3	E_4	E_5	E_6	E_7	
C_1	4	2	8	5	5	6	6	0.25
C_2	6	6	4	7	6	8	5	0.29
C_3	3	1	6	6	4	4	7	0.22
C_4	5	3	2	4	5	4	3	0.18
C_5	5	4	5	1	3	3	5	0.18
C_6	3	7	2	3	3	1	1	0.14
C_7	8	5	7	8	8	3	6	0.31
C_8	2	8	2	2	2	7	3	0.18

***3.5 Determination of final weight*.** Based on the results of tables 12 and 13**,** the final weighing was calculated by using equation 7. (See table 14).

Table 14. Final weighing

Criteria	W_{jA}	W_{jB}	W_{jA} x W_{jB}	W_{jD}
C_1	0.19	0.25	0.05	0.19
C_2	0.18	0.29	0.05	0.22
C_3	0.16	0.22	0.03	0.14
C_4	0.08	0.18	0.01	0.06
C_5	0.11	0.18	0.02	0.08
C_6	0.04	0.14	0.01	0.02
C_7	0.17	0.31	0.05	0.23
C_8	0.08	0.18	0.01	0.06

Step 4. Criteria evaluation

***4.1 Identification of information sources for criteria evaluation*.** Table 15 exhibits the information sources chosen to evaluate each criterion.

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Table 15. Evaluation method for each criteria

Criteria	Evaluation method	Company area
C_1	Company statistical records	Processes
C_2	Company statistical records	Production
C_3	Company statistical records	Processes
C_4	Company statistical records	Processes
C_5	Company statistical records	Processes
C_6	Experts participation	Logistics, Production, Maintenance, Engineering
C_7	Experts participation	Quality, Production, Product warehouse
C_8	Experts participation	Production, Logistics, Processes

4.2 Criterion evaluation. Based on statistical records the performance of the quantitative criteria ($C_1 \ldots C_5$) was obtained. Due to a confidentiality agreement, this information was omitted in the present paper. For the case of qualitative criteria (C_6, C_7, C_8) an expert method supported by an AHP, was used. As an example for the Line 1, the evaluation given by the Production Manager to criteria C_8 is shown in Table 16. By Applying equations 9 and 10, the obtained priority vector for this expert can be observed in table 17.

Table 16. Evaluation of Production Manager for C_8

ADP	Heat Treatment	Sharpen	Polish
Heat Treatment	1	1/4	1/9
Sharpen	4	1	1/5
Polish	9	5	1

Table 17. Priority vector for ADP according to Production Manager in C_8

ADP	Heat Treatment	Sharpen	Polish	Priority vector
Heat Treatment	0.07	0.04	0.08	0.07
Sharpen	0.29	0.16	0.15	0.20
Polish	0.64	0.80	0.76	0.73

As exhibited in Table 18, the final objective weight for C_8 is obtained by repeating the same procedure with the rest of experts. As can be observed, the most important ADP for Line 1 regarding C8 is Polish. This procedure must be repeated for the rest of qualitative criteria (C_6, C_7) and the remainder production lines.

Table 18. Qualitative Weight for ADP in C_8

ADP	Production Manager	Logistics Manager	Process Manager	Final weighting (S_f)
Heat Treatment	0.07	0.33	0.71	0.37
Sharpen	0.20	0.33	0.14	0.23
Polish	0.73	0.33	0.14	0.40

4.2.1 Consistency testing. Based on results shown in table 17, and according to equation 12, the resulting relative weights (R) were 0.196, 0.608 and 2.320 for Heat Treatment, Sharpen and Polish respectively. Consequently, by applying equations 13, 14 and 15, the obtained values for d_{max}, CI and CR were 3.072, 0.0362 and 0.0624 respectively. Therefore, due to the obtained value for CR was less than 0.1, it can be stated that the judgment of the Production Manager is consistent for line 1 and criterion C_8.

Step 5. ADP evaluation and selection

The quantitative and qualitative results of the eight evaluated criteria were collected. Then, as indicated in equations 16 and 17, the obtained data were homogenized and normalized. Subsequently, for each line and each ADP, Equation 18 allows to obtain the final grade (Q_p). Table 19 summarizes these results.

Table 19. Evaluation results for each ADP

Line	ADP	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	Final grade Q_p
Line 1	Heat Treatment	0.16	0.30	0.34	0.27	0.30	0.51	0.54	0.37	34.1%
	Sharpen	0.25	0.30	0.33	0.33	0.35	0.26	0.36	0.23	31.0%
	Polish	0.59	0.40	0.33	0.40	0.35	0.23	0.10	0.40	34.9%
Line 2	Heat Treatment	0.35	0.50	0.52	0.29	0.48	0.68	0.5	0.75	48.0%
	Paint and label	0.65	0.50	0.48	0.71	0.52	0.32	0.5	0.25	52.0%
Line 3	Heat Treatment	0.33	0.50	0.54	0.43	0.46	0.84	0.87	0.60	56.2%
	Sharpen	0.67	0.50	0.46	0.57	0.54	0.16	0.13	0.40	43.8%

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Line	ADP	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	Final grade Q_p
Line 4	Heat Treatment	0.31	0.50	0.53	0.43	0.37	0.86	0.87	0.37	53.7%
	Polish	0.69	0.50	0.46	0.57	0.63	0.14	0.13	0.63	46.3%
Line 5	Heat Treatment	0.45	0.50	0.53	0.46	0.5	0.75	0.87	0.61	58.8%
	Sharpen	0.55	0.50	0.47	0.54	0.5	0.25	0.13	0.39	41.2%
Line 6	Punch and mark	0.32	0.50	0.51	0.40	0.18	0.70	0.85	0.37	50.9%
	Clean	0.68	0.50	0.49	0.60	0.82	0.30	0.15	0.63	49.1%
Line 7	Weld	0.40	0.50	0.51	0.43	0.32	0.59	0.74	0.23	50.3%
	Sharpen	0.60	0.50	0.49	0.57	0.68	0.41	0.26	0.77	49.7%
Line 8	Heat Treatment	0.18	0.22	0.54	0.34	0.30	0.5	0.65	0.50	39.1%
	Straighten	0.82	0.78	0.46	0.66	0.70	0.5	0.35	0.50	60.9%
Line 9	Heat Treatment according to the experts									100%

Finally, based on the results of table 19, the ADP showing the greater grade at each production line were chosen. table 20 exhibit the selected decoupling points.

Table 20. Selected Decoupling Points

Production Line	Decoupling Point	Rating
Line 1	Polish	34.9%
Line 2	Paint and label	52.0%
Line 3	Heat Treatment	56.2%
Line 4	Heat Treatment	53.7%
Line 5	Heat Treatment	58.8%
Line 6	Punch and mark	50.9%
Line 7	Weld	50.3%
Line 8	Straighten	60.9%
Line 9	Heat Treatment	100%

CONCLUSIONS

The proposed methodology offers a new alternative for the DP location; taking into consideration a set of quantitative and qualitative criteria. Additionally, the participation of company experts allows the achievement of more realistic solutions in complex decisions. These decisions imply the proper balance between market requirements and company goals. In contrast to the identified solutions in literature review, this methodology is able to analyze the DP location for several production systems simultaneously.

Based on the obtained results, the analyzed company could locate the DP for its nine production lines. Due to several incident, criteria was considered and also the decision making was undertaken by a group of company experts. It is expected that the flexibility level of the company could be improved.

Finally, in order to enhance the proposed methodology, some aspects can be addressed. For example, by introducing the evaluation of the knowledge, the level and abilities of experts' reliability can be improved. Also, by applying simulation techniques, an *ex-ante* assessment can be addressed in order to analyze the real impact of the proposed solution in terms of efficiency and flexibility.

REFERENCES

[1] S. Kumar and J. Wilson, "A manufacturing decision framework for minimizing inventory costs of a configurable off-shored product using postponement", *Int. J. Prod. Res.*, vol. 47, n°. 1, pp. 143-162, Jan. 2009.

[2] A. Brun and M. Zorzini, "Evaluation of product customization strategies through modularization and postponement", *Int. J. Prod. Econ.*, vol. 120, n°. 1, pp. 205-220, Jul. 2009.

[3] K. A. Ferreira, R. N. Tomas, and R. L. C. Alcântara, "A theoretical framework for postponement concept in a supply chain", *Int. J. Logist. Res. Appl.*, vol. 18, n°. 1, pp. 46-61, 2015.

[4] L. Jiang, "The implications of postponement on contract design and channel performance", *Eur. J. Oper. Res.*, vol. 216, n°. 2, pp. 356-366, Jan. 2012.

[5] S. Guericke, A. Koberstein, F. Schwartz, and S. Voss, "A Stochastic Model for Implementing Postponement Strategies in Distribution Networks", *Proc. Annu. Hawaii Int. Conf. Syst. Sci.*, pp. 1-10, Jan. 2011.

[6] B. Yang, N. D. Burns, and C. J. Backhouse, "Management of uncertainty through postponement", *Int. J. Prod. Res.*, vol. 42, n°. 6, pp. 1049-1064, Mar. 2004.

[7] T. C. E. Cheng, J. Li, C. L. J. Wan, and S. Wang, "Application of Postponement: Examples from Industry", in *Postponement Strategies in Supply Chain Management*, vol. 143, New York, NY: Springer New York, 2010, pp. 125-132.

ISSN: 0122-3461 (*impreso*)
2145-9371 (*on line*)

[8] S. Wadhwa, K. S. Bhoon, and F. T. S. Chan, "Postponement strategies for re-engineering of automotive manufacturing: knowledge-management implications", *Int. J. Adv. Manuf. Technol.*, vol. 39, n°. 3-4, pp. 367-387, Dec. 2006.

[9] W. Alderson, "Marketing Efficiency and Principle of Postponement", *Cost Profit Outlook*, vol. 3, n°. 4, pp. 15-18, 1950.

[10] Y. Qin, "A Cost Model of Partial Postponement Strategy of the Single-Period Product under Stochastic Demand", *Res. J. Applied, Eng. Technol.*, vol. 4, n°. 11, pp. 1494-1499, 2012.

[11] S. Saghiri, "A structural approach to assessing postponement strategies: construct development and validation", *Int. J. Prod. Res.*, vol. 49, n°. 21, pp. 6427-6450, Nov. 2011.

[12] B. Yang and N. Burns, "Implications of postponement for the supply chain", *Int. J. Prod. Res.*, vol. 41, n°. 9, pp. 2075-2090, 2003.

[13] W. Liu, Y. Yang, H. Xu, X. Liu, Y. Wang, and Z. Liang, "A time scheduling model of logistics service supply chain based on the customer order decoupling point: a perspective from the constant service operation time.", *Sci. World J.*, vol. 2014, n°. 22, 2014.

[14] H. Rau and C. Liu, "Postponement strategies in Supply Chain Under the MTO production Environment", in *Proceedings of the Institute of Industrial Engineers Asian Conference 2013*, Y.-K. Lin, Y.-C. Tsao, and S.-W. Lin, Eds. Singapore: Springer Singapore, 2013, pp. 1289-1296.

[15] Y. Wang, W. Ye, J. Lin, and Y. Li, "A comparative study on mass customization mode with multiple CODPs and the one with single CODP", in *Proceedings of the 2012 24th Chinese Control and Decision Conference, CCDC 2012*, 2012, pp. 3295-3300.

[16] H. Shidpour, C. Da Cunha, and A. Bernard, "Analyzing single and multiple customer order decoupling point positioning based on customer value: A multi-objective approach", *Procedia CIRP*, vol. 17, pp. 669-674, 2014.

[17] A. Kasperski, *Discrete Optimization with Interval Data*, vol. 228. 2008.

[18] T. L. Saaty, "The Analytic Hierarchy and Analytic Network Measurement Processes: Applications to Decisions under Risk", *Eur. J. Pure Appl. Math.*, vol. 1, n°. 1, pp. 122-196, 2008.

[19] K. Seung Hwan and K. Joong-In, "Decision Framework for Customer Order Decoupling Point in a Semiconductor Supply Chain under Limited Capacity", *J. Korean Soc. Supply Chain Manag.*, vol. 13, n°. 1, pp. 1-15, 2013.

[20] W. Liu, Y. Mo, Y. Yang, and Z. Ye, "Decision model of customer order decoupling point on multiple customer demands in logistics service supply chain", *Prod. Plan. Control*, vol. 26, n°. 3, pp. 178-202, 2014.

[21] P. Hedenstierna and A. H. C. Ng, "Dynamic implications of customer order decoupling point positioning", *J. Manuf. Technol. Manag.*, vol. 22, n°. 8, pp. 1032-1042, 2011.

[22] Y. Wang, "Expert system for positioning of customer order decoupling point under mass customization", *Jisuanji Jicheng Zhizao Xitong/Computer Integr. Manuf. Syst. CIMS*, vol. 17, n°. 5, pp. 924-934, 2011.

[23] J. Cirullies, K. Klingebiel, and L. F. Scarvarda, "Integration of ecological criteria into the dynamic assessment of order penetration points in logistics networks", in *Proceedings 25th European Conference on Modelling and Simulation ECMS 2011*, 2011, pp. 608-615.

[24] L. Zhou and M. Li, "Location of Customer Order Decoupling Point in the Supply Chain of Deteriorated Food Based on Dynamic Model", *Adv. J. Food Sci. Technol.*, vol. 6, n°. 2, pp. 254-258, 2014.

[25] S. A. Fahmy, M. M. Mohamed, and T. F. Abdelmaguid, "Multi-layer dynamic facility location-allocation in supply chain network design with inventory , and CODP positioning decisions", in *2014 9th IEEE International Conference on Informatics and Systems (INFOS)*, 2014, pp. 14-23.

[26] W. Liu, H. Xu, X. Sun, Y. Yang, and Y. Mo, "Order Allocation Research of Logistics Service Supply Chain with Mass Customization Logistics Service", *Math. Probl. Eng.*, vol. 2013, pp. 1-13, 2013.

[27] H. Rafiei and M. Rabbani, "Order partitioning and Order Penetration Point location in hybrid Make-To-Stock/Make-To-Order production contexts", *Comput. Ind. Eng.*, vol. 61, n°. 3, pp. 550-560, 2011.

[28] N. R. S. Raghavan and N. Viswanadham, "Performance analysis of supply chain networks using Petri nets", in *Proceedings of the 38th IEEE Conference on Decision and Control (Cat. No.99CH36304)*, 1999, vol. 1, pp. 57-62.

[29] N. Viswanadham and N. R. S. Raghavan, "Performance analysis and design of supply chains: a Petri net approach", *J. Oper. Res. Soc.*, vol. 51, n°. 10, pp. 1158-1169, 2000.

[30] X. Y. Sun, P. Ji, L. Y. Sun, and Y. L. Wang, "Positioning multiple decoupling points in a supply network", *Int. J. Prod. Econ.*, vol. 113, n°. 2, pp. 943-956, 2008.

[31] J. Luo and Y. Han, "Positioning of CODP Based on Entropy Technology and Ideal Point Principle", in *2008 International Conference on Wireless Communications, Networking and Mobile Computing*, 2008, pp. 1-5.

[32] S. Hemmati, M. Rabbani, and M. Ebadian, "Positioning of order penetrating point in hybrid MTS/MTO environments", in *EMS 2009 - UKSim 3rd Euro-*

ISSN: 0122-3461 (*impreso*)
2145-9371 (*on line*)

pean Modelling Symposium on Computer Modelling and Simulation, 2009, pp. 263-268.

[33] E. Teimoury, M. Modarres, A. K. Monfared, and M. Fathi, “Price, delivery time, and capacity decisions in an M/M/1 make-to-order/service system with segmented market”, *Int. J. Adv. Manuf. Technol.*, vol. 57, n°. 1-4, pp. 235-244, 2011.

[34] Y. Qin and Y. Geng, “Production Cost Optimization Model Based on CODP in Mass Customization”, *IJCSI Int. J. Comput. Sci. Issues*, vol. 10, n°. 1, pp. 610-618, 2011.

[35] J. G. J. Ge, F. W. F. Wei, Y. H. Y. Huang, and G. G. G. Gao, “Research on customer order decoupling point positioning model for product life cycle”, *2009 Int. Conf. Mechatronics Autom.*, August, pp. 1083-1088, 2009.

[36] J. H. Ge, Y. T. Huang, Y. L. Xu, and G. A. Gao, “Research on supply chain cost optimization model of customized complex products and simulation”, in *2008 Asia Simulation Conference - 7th International Conference on System Simulation and Scientific Computing, ICSC 2008*, 2008, pp. 1334-1339.

[37] J. JI, L. Qi, and Q. GU, “Study on CODP Position of Process Industry Implemented Mass Customization”, *Systems Engineering - Theory & Practice*, vol. 27, n°. 12. pp. 151-157, 2007.

[38] M. Wu, F. Ma, H. Yang, and B. Sun, “Study on the customer order decoupling point position base on profit”, in *Proceedings of 2008 IEEE International Conference on Service Operations and Logistics, and Informatics, IEEE/SOLI 2008*, 2008, vol. 1, pp. 44-47.

[39] Y.-B. Zhang and J.-F. Chen, “The strategic positioning and optimization for decoupling point in an innovative product supply chain”, *J. Shanghai Jiaotong Univ.*, vol. 42, n°. 11, pp. 1832-1835, 2008.

[40] I. J. Jeong, “A dynamic model for the optimization of decoupling point and production planning in a supply chain”, *Int. J. Prod. Econ.*, vol. 131, n°. 2, pp. 561-567, 2011.

[41] C. Karrer, K. Alicke, and H.-O. Günther, “A framework to engineer production control strategies and its application in electronics manufacturing”, *International Journal of Production Research*, vol. 50, n°. 22. pp. 6595-6611, 2012.

[42] E. Teimoury, M. Modarres, F. Ghasemzadeh, and M. Fathi, “A queueing approach to production-inventory planning for supply chain with uncertain demands: Case study of PAKSHOO Chemicals Company”, *J. Manuf. Syst.*, vol. 29, n°. 2-3, pp. 55-62, 2010.

[43] E. Teimoury, M. Modarres, I. G. Khondabi, and M. Fathi, "A queuing approach for making decisions about order penetration point in multiechelon supply chains", *Int. J. Adv. Manuf. Technol.*, vol. 63, n°. 1-4, pp. 359-371, 2012.

[44] W. Zhou, W. Huang, and R. Zhang, "A two-stage queueing network on form postponement supply chain with correlated demands", *Appl. Math. Model.*, vol. 38, n°. 11-12, pp. 2013-2015, 2014.

[45] J. Ashayeri and W. Selen, "An application of a unified capacity planning system", *Int. J. Oper. Prod. Manag.*, vol. 25, n°. 9, pp. 917-937, 2005.

[46] E. Teimoury and M. Fathi, "An integrated operations-marketing perspective for making decisions about order penetration point in multi-product supply chain: a queuing approach", *Int. J. Prod. Res.*, vol. 51, n°. 18, pp. 5576-5596, 2013.

[47] H. Rafiei and M. Rabbani, "An MADM Framework toward Hierarchical Production Planning in Hybrid MTS / MTO Environments", in *World Academy of Science, Engineering and Technology*, 2009, vol. 58, pp. 462-466.

[48] J.-M. Lehtonen, "Choice of order penetration point in the Nordic paper industry environment", *Pap. ja Puu/Paper Timber*, vol. 81, n°. 3, pp. 196-199, 1999.

[49] D. Liu, W. Wang, and W. Fu, "CODP position of leagile supply chain based on polychromatic sets theory", in *Proceedings of the 2009 IEEE International Conference on Automation and Logistics, ICAL 2009*, 2009, n°. 10872160, pp. 432-437.

[50] Y. Huang, G. Wang, B. Ren, and H. Zhang, "CODP Positioning and Optimization of Complex Product Life Cycle Supply Chain", *INFORMATION-AN Int. Interdiscip. J.*, vol. 15, n°. 11, pp. 4603-4608, 2012.

[51] S. Chand and M. Wagner, "Evolutionary Many-Objective Optimization : A Quick-Start Guide", *Surv. Oper. Res. Manag. Sci.*, vol. 20, pp. 1-28, 20015.

[52] M. Xiuli, "Research on position conflict of customer order decoupling point for instant customerization", in *2011 International Conference on E-Business and E-Government, ICEE2011 - Proceedings*, 2011, pp. 4409-4412.

[53] T. L. Saaty, "Decision making with the analytic hierarchy process", *Int. J. Serv. Sci.*, vol. 1, n°. 1, p. 83, 2008.

[54] C.-C. Chou, "An integrated quantitative and qualitative FMCDM model for location choices", *Soft Comput.*, vol. 14, n°. 7, pp. 757-771, 2009.

[55] W. A. Sarache, C. Hoyos Montoya, and J. C. Burbano J, "Procedimiento para la evaluación de proveedores mediante técnicas multicriterio", *Sci. Techica*, n°. 24, pp. 219-224, 2004.

ISSN: 0122-3461 (*impreso*)
2145-9371 (*on line*)

[56] C. N. Verdouw, A. J. M. Beulens, D. Bouwmeester, and J. H. Trienekens, "Modelling Demand-drive Chain Networks using Multiple CODPs", in *Lean Business Systems and Beyond*, vol. 257, 2008, pp. 433-442.

[57] A. H. Perera, C. A. Drew, and C. J. Johnson, *Expert Knowledge and Its Application in Landscape Ecology*. 2012.

[58] M. Cruz and M. C. Martínez, "Perfeccionamiento de un instrumento para la selección de expertos en las investigaciones educativas", *Rev. Electrónica Investig. Educ.*, vol. 14, n°. 2, pp. 167-179, 2012.

[59] W. A. Sarache-castro, Y. J. Costa-salas, and J. P. Martínez-giraldo, "Environmental performance evaluation under a green supply chain approach", *DYNA*, vol. 82, n°. 189, pp. 207-215, 2015.

[60] M. Muskat, D. Blackman, and B. Muskat, "Mixed methods: Combining expert interviews, cross-impact analysis and scenario development", *Electron. J. Bus. Res. Methods*, vol. 10, n°. 1, pp. 9-21, 2012.

[61] S. C. William Ariel, O. D. Castrillón, G. Gonzales, and A. Viveros Folleco, "A multi-criteria application for an equipment replacement decision", *Rev. Científica Ing. y Desarro.*, vol. 25, n°. 1, pp. 80-98, 2009.

[62] T. Saaty, "The analytic hierarchy process", New York McGraw-Hill, 1980.

[63] R. W. Saaty, "The analytic hierarchy process—what it is and how it is used", *Math. Model.*, vol. 9, n°. 3-5, pp. 161-176, 1987.

[64] F. Marrero Delgado, "Procedimientos para la toma de decisiones logísticas con enfoque multicriterio en la cadena de corte, alza y transporte de la caña de azúcar. Aplicaciones en el CAI de la provincia de Villa Clara", Universidad Central "Marta Abreu" de Las Villas, 2011.

[65] F. R. Manuel A, H. A. Rafael, P. B. Fabio M, R. V. Sara A, and V. c. Manuel, "Implementación de fem para la mejora tecnológica del diseño de forja en caliente en herragro S. A.", in *Segundo Congreso Internacional AMDM.*, 2014, pp. 71-79.

[66] X. G. Xu, "Position of customer order decoupling point in mass customization", in *Proceedings of the Sixth International Conference on Machine Learning and Cybernetics, ICMLC 2007*, 2007, vol. 1, pp. 302-307.