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L.A.R.G. supplier selection based on integrating house of quality, Taguchi loss function and M.O.P.A.

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ABSTRACT

Nowadays, companies are able to obtain the key to success in global competition by choosing the right suppliers who are more align with their strategies. It is clear that applying appropriate attitudes and criteria have a great importance in choosing suppliers in the process of decision-making by chain managers and especially purchasing managers. In this study tried to apply Lean, Agile, Resilient and Green (L.A.R.G.) approach in a model designed to select the consistence supplier. Accordingly, at first, while reviewing and exploiting the literature, the most main logistics needs of the company concerned in the light of the objectives that followed on the fields of the LARG attitudes, are refined and selected, then their degree of significance is determined through Multi-Objective Performance Analysis (M.O.P.A.). The house of quality (H.O.Q.) matrix is applied to determine the importance degree of the technical characteristics of the suppliers and Taguchi loss function is applied to determine the degree of their performance deviation from the target value in each one of the technical characteristics (ultimate judgment about their competency). The considered suppliers are ranked based on the results of the loss function analysis. A sensitivity analysis was conducted to analyse the impact of different conditions on suppliers' ranking and validation of the ranking results were Satisfied by applying the T.O.P.S.I.S. method.

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L.A.R.G. supply chain; supplier assessment; multi-objective performance analysis; house of quality (H.O.Q.); Taguchi loss function; T.O.P.S.I.S

1. Introduction

Supply Chain Management (S.C.M.) is defined as the network management of interconnected businesses involved in providing final products and the customer's services. S.C.M. covers all essential replacement related to raw material, work in process and finished goods from the point of origin to the point of consumption (Cetinkaya et al. 2011).

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S.C.M. is became a technical asset compatibilty with modern global competition, and S.C.M.'s strategies, In S.C.M., what is required is how to improve the performance. Supply chains, in an attempt to be more competitive, are adopting new management paradigms. Among these paradigms, there are four that deserve particular mention because of their importance to better supply chain performance: Lean, Agile, Resilient and Green (L.A.R.G.) paradigms (Hassan, Nabil, & Rady, 2015). Performance measurement is crucial to better S.C.M. The lack of appropriate metrics for these measurements could be the main reason responsible for the following failure breakdowns in the supply chains: inability to meet customer satisfaction; sub-optimisation of firms' performance; loss of opportunities to outperform the competition; and creation of conflicts within the supply chain.

In most industries, the cost of raw materials and components of the product constitutes a great part of the finished goods cost (Ghodsypour & O'Brien, 1998). In such a situation, the logistic function can contribute greatly to the efficiency and effectiveness of the organisation and have a direct effect on reducing costs, increasing profitability and flexibility (Ghodsypour & O'Brien, 2001). Since contemporary organisations have become more supplier dependent, so risk and direct and indirect consequences caused by poor decision-making are more acute (De Boer, Labro, & Morlacchi, 2001). In fact, choosing a good potfolio of suppliers is very important and vital in the success of a company, (Zhang, Zhang, & Chen, 2010). Selecting the right supplier and managing it is a measure that can be adopted to increase the competitiveness of the supply chain (Lee, Ha, & Kim, 2001). To this aim, Supplier Performance Measurement Systems (S.P.M.S.s), defined as a as a set of metrics used to quantify the efficiency and effectiveness of suppliers' actions (Hald & Ellegaard, 2011) have become critical.

Firms, with the right choice of suppliers that meet their objective and perspectives, are able to hold the key to success in the global competitive markets. Since the process of choosing the right supplier able to meet the buyers' needs as to quality product at proper price, timing and amount, requires serious consideration and attention regarding various characteristics and criteria (Narasimhan, Talluri, & Mahapatra, 2006), make the number of suppliers limited. An increase in goods and services, make the process of setting criteria more complex thus more complex decision-making process in selecting suppliers. This procedure requires more systematic and scientific approach if meeting the objectives is sought. The S.P.M.S. is essential to facilitate and direct the performance communication between the buyer and the supplier company. In a signal sent-received scenario, the S.P.M.S. is a way to condense and formalise the buyer company feedback on supplier performance.

L.A.R.G. S.C.M. is struggling to put together the mentioned attitudes above in the S.C.M.'s environment, by applying the advantages of these approaches and fix existing shortcomings in a simultaneouse manner (Azevedo, Carvalho, & Cruz-Machado, 2011). Consequently, new intellectual movements are proposed to streamline these attitudes in tactical and operational decisions regarding the S.C.M., this research focuses in particular on the extensive overview on supply chain paradigms (L.A.R.G.) and indicate the performance indicators associated with each paradigm so that be able to provide a model to evaluate and improve supply chain performance continuously. The Computational results of applying the mentioned model evaluates the suppliers' performance and enables us to choose the best of them.it seems that the simultaneous integration of L.A.R.G. paradigms in S.C.M. may help supply chains to become more efficient and streamlined.

In this study, an integrated method of Taguchi loss function, House Of Quality (H.O.Q.) and Multi Objective Performance Analysis (M.O.P.A.) is proposed to solve the supplier selection problems. First, the M.O.P.A. is used to calculate the relative weight of each technical characteristic; Second, The Taguchi loss function is applied to assess the loss of each selection characteristic. Finally, based on the degree of supplier performance deviation from the target value in each one of the technical characteristics, the best supplier can be identified.

The article is organised as follows. Section 1 presents an introduction. In Section 2 we review relevant scientific literature addressing classification and discussing the S.C.M. paradigms in some details. In Section 3, methods and materials are presented. In Section 4, application results and in Section 5 sensitivity analysis were obtained. The conclusion and a discussion are outlined in Section 6.

2. Theoretical framework and literature review

In the 1980s the focus of organisations was more on systems like Just In Time (J.I.T.), Total Quality Management (T.Q.M.), etc., with the objective to achieve sustainable competitive advantage, they did not achieve the planned sustainability because these competitive advantages were all being copied by competitors. Efforts to optimise organisational processes, regardless of external partners, like suppliers and customers is specific, was assumed useless by individual outfits, but organisations that worked together to achieve common objectives recorded better performance. It was then, when the concept of the supply chain emerged (Stavrulaki and Davis, 2010). The Council of Supply Chain Management (C.S.C.M.) defined the S.C.M., as 'integration key business processes from major suppliers to final user, so that provides products, services and information that provide added value for customers and other stakeholders' (Rimiene, 2011).

2.1. L.A.R.G. supply chain management

The idea of L.A.R.G. Supply Chain Management is emerged and developed at the Research Department for Mechanical and Industrial Engineering, Faculty of Science and Technology, New University of Lisbon. At present, this research center is recognised as the main reference in this field. L.A.R.G. strategies are now at the forefront of management practices for S.C.M. Each one of the four supply chain approaches has its advantages and disadvantages. Applying the advantages and planning to eliminate the disadvantages of each one of these approaches would increase the value creation potential in the supply chain (Carvalho & Cruz-Machado, 2011). In terms of the L.A.R.G. combined approach, the selection of suppliers is based on the integration of the available in each one of the pure, agile, resilience and green perspectives. Jamali et al. (2017) also analysed L.A.R.G. Supply Chain Management competitive strategies of cement strategies. Hassan et al. (2015) presented new approaches in management through a model developed by them assess and improve the supply chain function, in order to minimise the total cost of the system and meet the customers' needs. Among these approaches, five patterns with a significant impact on improving the supply chain function that deserve particular attention consist of: Lean, Agile, Resilience, Green, and Talentship, introduced as L.A.R.G.T. Approaches. They conducted a comprehensive review of the supply chain (L.A.R.G.T.) in order to improve the supply chain function and introduced function indexes in relation to each approach that their application in S.C.M. would improve the chain function.

Carvalho, Azevedo and Cruz-Machado (2014) in a study on automotive industry, concluded what is important to the automaker and should be prioritised in the development and improvement programs, is the quality, followed by, are flexibility, delivery, cost and, ultimately, environmental protection. They stated that the selected indexes for better management of the supply chain in each of the four approaches are as follows:

Lean: timely manufacturing and geographic focus with suppliers, Agile: multi-product manufacture system and transport synchronisation with manufacture, flexible: strategic stocks and flexible transportation, Green: ISO 14001 certification and environmentally friendly packaging. Azfar (2012) in seeking to find common grounds for integrating and balancing the key supply chain factors in a L.A.R.G. approach concluded that reduction in transport distance, order execution time, and cost can provide the best opportunity for combining chain factors. This opportunity can provide common grounds or a space where replacement, alignment or even integration of important supply chain factors meet and perform in L.A.R.G. Cabral, Grilo, and Cruz-Machado (2012) assessed the S.C.M. approach through network analysis process technique in the Volkswagen automotive industry. They considered the four indexes of time, cost, service level and product quality as the key elements in supply chain function. Carvalho, Duarte, and Cruz Machado (2011), state that each one of the lean, agile, resilience, and green approaches assess the supply chain in a particular context. The objective of 'Lean approach' is to minimise inventory, volume of resource utilisation, information expansion through the network, producing in a timely manner and shortening latency. In agile approach maintaining inventory to meet demand, additional buffer capacity, rapid response to consumer needs, whole market perspective, dynamic unity, supplier speed, flexibility, quality and shortening latency as its core requirements are of concern. The resiliency chain is involved in states activities like strategic inventory, buffer capacity, and demand visibility, production in small and large scales, accountability, risk sharing, and flexible transport. In the green supply chain reducing waste and unnecessary requirements, reducing refilling, increasing the integration of materials and information flows in the supply chain, sharing environmental risk, minimising wastes, reducing transport time, utilising resources are of major concern. Although the nature of these approaches sometimes changes, in general, they complement each other, and none of them are better or worse than others. Maleki, da Cruz, Valente, and Machado (2011) provided a general comparison among lean, agile, resilience and green patterns. They compared the four approaches based on the 10 components of: goal, production concentration, unity with suppliers and customers, organisational structure, supplier selection approach, inventory level, focus on latency time, market, product diversity and the product design approach with one another. In most of the studies, researchers have sought to identify different criteria in the fourfold approaches of this problem and have applied them in designing a supply chain model with a competitive advantage through L.A.R.G. problem and eventually combining these paradigms. They acknowledged that the presentation of this pattern causes comparative advantage gain through less process costs, less time waiting, more product quality and more flexibility, more responsiveness and more satisfaction for customers.

2.1.1. Lean Supply Chain Management (L.S.C.M.)

Lean strives to identify and eliminate all non-value added activities which are a potential source of improvement in any kind of business process. The perception of lean is the reduction of waste and the subsequent cost reduction, quality improvement, better use of resources and deliver value to customers (Pakdil & Leonard, 2014). Different definitions of the lean can be found in the related literature, but they all share the general principle, that is, minimising costs and eliminating wastes. Basic concept of lean is synonymous with more work with fewer resources (for example less manpower, equipment, time and space), while being closer to meeting the needs of the customer. According to Pakdil and Leonard (2014) the management based on lean principles enables organisations to gain increasingly high levels of efficiency, competitiveness at the lowest cost, with high levels of productivity, speed of delivery, minimum stock levels and optimum quality. Lean should be developed throughout the organisation and requires a climate of innovation, an infrastructure to support it, and complete management commitment (Wyton & Payne, 2014).

Companies must adopt lean, both internally and externally, spreading lean principles and practices through the whole supply chain in order to achieve all the potential benefits of this philosophy. Lean principles are, therefore, applicable to the whole SC, from the provider to the final distributor and the final customer delivery, which is known as Lean Supply Chain Management (L.S.C.M.) (Tortorella, Miorando, & Marodin, 2017). In order to adopt lean principles, companies can apply diverse L.S.C.M. practices. Cabral et al. (2012) also explained how L.A.R.G. S.C.M. is necessary for the modern business environment in all around the world and a decision-making framework based on A.N.P. method presented for that. Liu, Leat, Moizer, Megicks, and Kasturiratne (2013) applied a decision-focused knowledge framework with multi-layer knowledge model to support collaborative decision-making for lean S.C.M.

2.1.2. Agility Supply Chain Management (A.S.C.M.)

Supply chain agility is the ability of a supply chain to react to changes in business environments in a timely manner (Swafford, Ghosh, & Murthy, 2006). An agile supply chain is a combination of business partners applied in empowering new enterprises in order to react to market changes that result from customised products and services in a quickly and effective manner. The most prominent feature of agility, observed in most of its definitions, is the ability to respond to market changes in a rapid manner as a key component to assure the success and survival of firms in the market (Charles, Lauras, & Van Wassenhove, 2010). Gligor and Holcomb (2012) described supply chain agility in terms of responsiveness, change as opportunity, flexibility, customisation, mobilisation of core competencies, integration, organisational structure and speed. The study of Gligor, Holcomb, and Stank (2013) also identifies environmental uncertainty, supply chain and market orientation as antecedents of firm supply chain agility. Alimardani, Zolfani, Aghdaie, and Tamošaitienė (2013) also presented a new hybrid M.A.D.M. method based on S.W.A.R.A.-V.I.K.O.R. methodologies for supplier selection in the agile environment.

2.1.3. Resilient Supply Chain Management (R.S.C.M.)

Resilience is one of the issues that have been widely addressed in the recent in the supply chain literature. Resilience is the expanded form of the traditional notion of resistance and is defined as measures, which increase the function of structures, elements of infrastructure and institutions, through reducing losses caused by crisis. Although focus of resilience against crisis is more on crisis prevention and reduction, the efforts there of upon occurrence goes beyond this concept and enhances the function and flexibility of a system both before and after crisis. Accordingly, the supply chain can be defined as the ability of a chain in reducing the existing probabilities, reduce the consequences of the disorder, if any (as soon as it occurs), and reduce the recovery time of the normal system's state. In general resilience is the ability to deal with crisis and unexpected events. The objective of this concept is to restore the supply chain after crises in the shortest time and the least cost (Falasca, Zobel, & Cook, 2008). Juttner and Christopher (2003) define resilience as the identification of potential risk sources and the implementation of appropriate strategies in a coordinated manner among supply chain members in order to reduce supply chain vulnerability. Mathematically, this vulnerability can be measured as the combination of the occurrence probability of an unexpected event and its potential impact on the supply chain performance (Pettit, Fiksel, & Croxton, 2010). Haldar et al. (2012) applied a hybrid M.A.D.M. model for evaluating suppliers based on resilient approach. Chowdhury and Quaddus (2015) proposed a new model based on Multi-objective model, A.H.P. and Q.F.D. for efficient resilient strategies.

2.1.4. Green Supply Chain Management (G.S.C.M.)

Green S.C.M. .initially introduced by the Michigan State University Research Association in 1996 with the purpose of increasing the utility rate of resources and energy and reduces environmental impacts caused by the producing of some specific products (Jia & Bai, 2011). Bowen et al. (2002) identify three levels of action in the implementation of green supply practices: greening the supply process, product-based green supply and advanced green supply. They tried to explain why companies still do not implement green supply practices, although beneficial in theory, in their day to day activity. The Green S.C.M. has emerged as a popular corporate philosophy for achieving corporate objectives related to market share and profit, along with a reduction in environmental risks and the effects thereof (Carvalho & Machado, 2011). The objective of G.S.C.M. approach is to eliminate and reduce any waste in resources or energy along the supply chain (Ninlawan et al., 2010).Yazdani et al. (2017) applied Q.F.D. and a new hybrid M.A.D.M. model based on D.E.M.A.T.E.L., C.O.P.R.A.S. and M.O.O.R.A. for the green supplier selection. Tsui, Tzeng, and Wen (2015) presented a hybrid M.A.D.M. model based on P.R.O.M.E.T.H.E.E. and Influential Network Relation Map (I.N.R.M.) for the supplier selection and evaluation. Mathiyazhagan, Govindan, and Haq (2014) studied on pressure analysis for green S.C.M. implementation based on A.H.P. method. Kusi-Sarpong et al. (2015) implemented Fuzzy T.O.P.S.I.S. in Green supply chain practices assessment in the mining industry. Akman (2015) applied Fuzzy V.I.K.O.R. for evaluating suppliers based on green development programs. Leif Tramarico, Pamplona Salomon, and Silva Marins (2017) used A.H.P. for evaluation of the benefits of a S.C.M. training considering green topics. Zhao et al. (2017) proposed a model based on a multi-objective optimisation model for green S.C.M. by applying a big data analytic approach. Nurjanni, Carvalho, and Costa (2017) presented a mathematical model for designing a green S.C.M. model. Chatterjee, Pamucar, and Zavadskas (2018) applied R'.A.M.A.T.E.L.-M.A.I.R.C.A. for green supply chain implementation in electronics industry. Jiang et al. (2018) applied D.E.M.A.T.E.L. and Grey D.A.N.P. for green supplier selection.

2.2. Review of the supplier selection methods

Methodologies for supplier evaluation have included conceptual, empirical and modelling approaches. Some the conceptual research primarily emphasises the strategic importance of supplier evaluation and the trade-offs among cost, quality and delivery performance. The empirical research mainly focuses on studying the relative importance of various supplier attributes such as price, quality and delivery performance (Talluri & Narasimhan, 2003). Important models are summarised below:

2.2.1. Categorical model

In the categorical model (Willis & Houston, 1990; Zhu, 2008; Venugopalan, Sarath, Pillai, Krishnan, & Anbuudayasankar, 2014), suppliers are evaluated by criteria such as cost, quality, speed of delivery, etc. With regard to each criterion, suppliers are classified as good, fair, poor and assigned a (+), (0) or (−) for each level, respectively.

2.2.2. Cost–ratio method

This model collects all costs related to quality, delivery and service and evaluates them as a percentage of the total price. Then, the supplier who can provide the lowest cost is the best choice (Humphreys, Mak, & Yeung, 1998; Patil & Kumthekar, 2016).

2.2.3. Cost-based models

Monczka and Trecha (1988), recognised that material price is only a fraction of the cost of the purchased material and that the measurement and evaluation of the supplier's performance should accurately reflect the total cost of doing business with that individual supplier. Hence, they provided a cost-based supplier performance evaluation system to reflect the actual total cost of doing business. In this model, two indices, namely a supplier performance index (S.P.I.), and a service factor rating (S.F.R.) were used. The S.P.I. recognises costs attributed to non-performance by suppliers for delivery, material quality and price. These costs are identified and collected after which the total cost of the supplier's performance is used to develop an index number for each supplier for each major item.

2.2.4. Weighted point model

The weighted point method (Timmerman, 1986), quantifies the factors with relevant weights and then rates the potential suppliers according to these weighted factors. Thompson (1990) stated that this decision begins with the identification and weighting of key dimensions (evaluative or choice criteria) required for evaluating alternative vendors. The decision-makers next rate the expected performance of the suppliers by each evaluation criterion under intuitive judgment. The supplier performance ratings are multiplied by their respective importance weights to yield a weighted value. Then, the vendor with the highest summated score is the superior choice (Khaled et al., 2011; Wei et al., 2017).

2.2.5. Vendor profile analysis

This model incorporates decision-makers' understanding of uncertainty surrounding vendor performance by using a Monte Carlo simulation technique instead of a rating from human intuitive judgment. The simulation algorithm randomly samples values from within each estimated performance range and combines these values with importance weights, in accordance with linear compensatory rules, to produce a distribution of summated scores. This process can be repeated up to several thousand times for each supplier (Anyaeche & Abegunde, 2013).

2.2.6. Dimensional analysis

In this model, the evaluation process involves a series of one-on one comparison and can compare only two suppliers each time. The Dimensional Analysis (D.A.) ratio can be greater than 1, equal to 1 or less than 1. Youssef, Zairi, and Mohanty (1996) pointed out that this evaluation method has two disadvantages. First, a value of D.A. = 1 will cause the decision-maker to be indifferent about which supplier is chosen. Second, the process becomes very tedious and time-consuming if a large number of suppliers must be evaluated (Roach, 2011).

3. Materials and methods

3.1. Multi Objective Performance Analysis (M.O.P.A.)

Multi Objective Performance Analysis (M.O.P.A.) technique is a new approach in Multi-Criteria Decision-Making techniques and Introduced by Dey et al. (2016). They propose to modify the direct or initial weights of the criteria. This attempt of modified weight concept was primarily meant for reducing the degree of inherent inaccuracy involved with expert's assessment in direct application of the weights.

This algorithm maximises the benefit criteria and minimises the cost criteria to calculate the Final Selection Index (F.S.I.) of the alternatives thorough a few intermediate steps. One of the advantages of this method is its accuracy, simplicity, feasibility and applicability. In order to assure the consistency and accuracy of this technique, the results obtained from the M.O.P.A. algorithm have been compared with other proven M.C.D.M. methods such as T.O.P.S.I.S., S.A.W., M.O.O.R.A., E.L.E.C.T.R.E. II and V.I.K.O.R. Comparasions of analysis run indicate that the results obtained from this method are more accurate and stable in solving multi-objective decision problems. Analyses Of Variance (A.N.O.V.A.) and sensitivity indicate that the concept of innovative modified weight reduces the relative dispersion of weight in a significant manner and leads to drawing accurate decisions. Therefore, the M.O.P.A. technique is known as a simple, strong, effective, and accurate decision-making tool. The steps to implement the M.O.P.A. algorithm consist of:

Step 1: formation an expert team, where the members, are represented by $D_1, D_2, \ldots D_P$, to choosing the most important and most effective one among the requirements of logistics services in each of the paradigm, and display marked by the following symbols:
Logistics requirements in the Lean Approach: $L_1, L_2, \ldots, L_m$
Logistics requirements in the agile approach: $A_1, A_2, \ldots, A_m$
Logistics requirements in the resilience approach: $R_1, R_2, \ldots, R_m$
Logistics requirements in the Green Approach: $G_1, G_2, \ldots, G_m$
Then the team members will assess these needs, which are represented with $C_1, C_2, \ldots, C_n$as total.
Step 2: Form the matrix of weights, where each expert allocates weight to each logistics requirement to this matrix based on their importance as follows:

$$W = \begin{array}{c} \\ C_1 \\ \cdots \\ C_j \\ \cdots \\ C_n \end{array} \begin{array}{c} \begin{array}{ccccc} D_1 & \cdots & D_K & \cdots & D_p \end{array} \\ \begin{bmatrix} \tilde{w}_{11} & \cdots & \tilde{w}_{1k} & \cdots & \tilde{w}_{1p} \\ & & & & \\ \tilde{w}_{j1} & \cdots & \tilde{w}_{jk} & \cdots & \tilde{w}_{jp} \\ & & & & \\ \tilde{w}_{n1} & \cdots & \tilde{w}_{nk} & \cdots & \tilde{w}_{np} \end{bmatrix} \end{array}$$

where, $\tilde{w}_{jk}$ = weight of the jth need determined through kth decision-maker.
Step 3: the weights' mean are determined through the following equation:

$$\tilde{w}_j = \frac{1}{p}\sum\nolimits_{k=1}^{p} \tilde{w}_{jk}$$

Step 4: normalise the weights obtained from step 3 through the following equation to allow their comparison

$$w_j^N = \frac{\tilde{w}_j}{\sum_{j=1}^{N} \tilde{w}_j} \; for \; j = 1, \ldots, n, \; 0 \le w_j^N \le 1$$

Step 5: calculate the adjusted weights of the logistics equirements of the company. The weight of these needs is based on the judgment of the experts according to the past experience and in accordance with the technical characteristics of the logistics services' design, which are not always accurate. For this purpose, weighted values are applied to reduce this inaccuracy to a large extent. Adjusted weights are calculated through the following equation:

$$w_j^M = \left(1 - w_j^N\right)^{\bar{w}_j^N} / \sum_{j=1}^{M} w_j^M$$

For the steps that should follow these weights enter the H.O.Q. matrix.

3.2. Taguchi Loss Function

Taguchi Loss Function is a high-quality, prominent engineering method applied in solving various issues, regarding assessment and selection for suppliers is specific. It is common in most quality control methods where if the measured specifications of a product are in a certain range, the product is of quality and acceptable. Taguchi's Loss function limits its viewpoint and shows more sensitivity to the subject. Taguchi defines quality as a social loss consequence from the production of a product after it is sent to the customer. According to Magdalena (2012), loss in question is the cost of maintenance, the cost of failure, adverse effects to the environment such as pollution or excessive production cost. In this context, a loss function can be applied to reflect the losses associated with deviations from the target value. Applying the classical approach in control charts requires that, when the quality attribute is not within control limits, the quality losses of concern as cost, and all products within the control limits, regardless of the deviation of their qualitative characteristic with respect to the target value must have the same quality. This requirement does not hold true in reality, because any deviation from the ideal value, introduces propotional loss to customer. In the loss function, there exist a loss for any change or deviation from the target value, even if the control statistics is within the control limit and the loss is equal to zero, only at the target point. Accordingly, the Taguchi's non-linear loss function can be applied to determine the quality loss of a product when its quality characteristic is deviated from the target value, in a sense that a product with a quality attribute within the control range will imopose a cost proportional to its squared deviation from the target value. Consequently, the difference between two products within the control limits, one close to ideal and one close to the control limits of the chart are of concern in this approach, and this is the main advantage of applying the Taguchi loss function.

Applying the Taguchi loss function to estimate the losses caused by the supplier's performance corresponds to the following steps:

Step 1: Determine target value and acceptable tolerence of specifications for each technical specification of L.A.R.G. supplier by the decision-maker.

Step 2: Calculate the loss coefficient in the Taguchi function. The coefficient value (K constant) of the loss for each technical characteristics is calculated through the following equation:

$$K = \frac{100}{(LSL\ or\ USL)^2}$$

where, USL is the upper limit of specification, LSL is the Lower limit of specification

Step 3: Estimate and assess the suppliers' performanceaccording to each technical characteristic based on the past trend analysis. Supplier's performance is expressed by x_i_j and the j-suplier performance is expressed in accordance with characteristic i. The number of considered suppliers is expressed by M.

Step 4: Calculate the Taguchi loss for each supplier's technical specification through the following equation:

$$l_{ij} = k_i(x_i - x_{ij})^2\ for\ i = 1, \ldots, N,\ j = 1, \ldots, M$$

where, l_{ij} is the loss value caused by the jth-supplier in the ith characteristic

Step 5: Calculate the total weighted loss for each supplier according to technical characteristic and based on the weights obtained from the H.O.Q. matrix. The weighted loss of these characteristics are calculated through the following equation:

$$l_j = \sum w_i l_{ij}\ for\ i = 1, \ldots, N,\ j = 1, \ldots, M$$

$l_j =$ is the Weighted sum of loss for Performance of supplier j in all technical characteristics.

3.3. Information about cooperated experts

In the process of research more than 10 experts have been cooperated and all information about them is accessable through the Table 1.

4. Implementation

The purpose of this section is to explain the proposed conceptual model in assessing and selecting the L.A.R.G. suppliers in a case study of the home appliance industry. The referred process has three phases, are shown in Figure 1.

Table 1. Experts' information.

Expert no.	Position	Education	Work experience (year)
1	Deputy Commerce	PhD	11
2	Director of the Center of Technology	PhD	8
3	Director of identifying and assessment suppliers	Master	12
4	Purchase manager	Master	5
5	Expert of commerce	Master	14
6	Expert on foreign buying	Master	13
7	Foreign Trade Expert	Master	7
8	Programming expert	Master	6
9	Director Trading	Master	15
10	Purchase expert	Bachelor	12
11	Purchase expert	Bachelor	12
12	Purchase expert	Bachelor	14

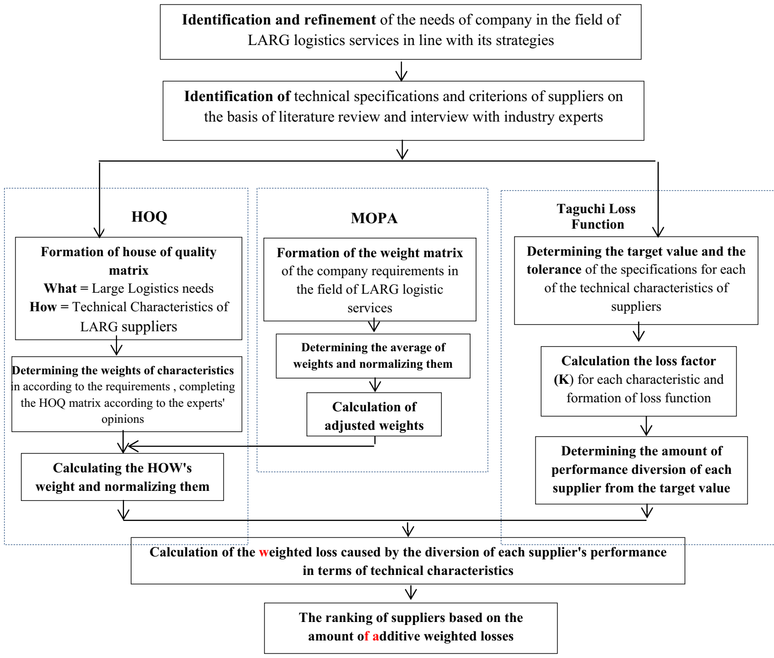


Figure 1. Research conducting process.

Table 2. L.A.R.G. logistics' needs in case study assessment.

Index	Sub-index
Lean	Removal of wastes
	Reduction in costs
	Increase in quality
Agile	Flexibility
	Improving the accountability
	Speed of performing
Resilience	Reliability
	Crisis Management
	Consistency or compatibility
Green	Minimising environmental damages
	Reverse logistics
	Pollution control

Initially, the objectives and strategies of the company in the field of L.A.R.G. logistics services are identified, analysed in content and refined through running targeted interviews with the experts of the research population. L.A.R.G. logistic needs in the case study assessment are tabulated in Table 2.

The requirements mentioned are weighted through the M.O.P.A. technique and according to judgments made by the experts, and are placed in the W.H.A.T. column in the matrix of the H.O.Q. encounters the technical characteristics of the L.A.R.G. supplier (H.O.W.).

In order to identify and refine the related components regarding the H.O.Q. matrix (technical characteristics) both the findings in the related literature and the opinions of experts in this field are applied. The requirements of the L.A.R.G. approaches are given to expert group after extraction and by analysing the content of

Table 3. Initially requirements and selected technical characteristics.

LARG requirements	Technical characteristics
Lean: Delivery reliability, timely delivery, timely production, compliance of products with specifications, high quality of parts, competitive price, cost control, low costs of wrong delivery, after sales service, warranty period of parts, ease in maintenance and repair, reduce startup time, history/ long experience in supply.	Delivery reliability-Timely production-Matching products with specifications -High quality of parts -competitive price
Agile: production based on order, responsiveness to urgent orders, customer satisfaction, ability to change production volume, ability to supply diverse models of Needed market, defective product compensation rate, product customisation speed, product variety.	Production based on order –Response to urgent orders –Customer satisfaction The ability to change the volume of production – Product customisation speed
Resilience: Performing commitments towards material supply contracts, payment method, technical cooperation, time of construction, consistent with the supply chain, transparency of supply conditions, applying new technologies, demand-driven management, employing specialised labor, knowledge and technology transfer, accept damages in transportation, coordination with the existing fleet	Carrying out obligations towards material supply contracts-payment method Technical cooperation's –Transparency of supply conditions-Construction time consistent with the supply chain
Green: Low wastes rate, using recycled pallets for material delivery, low emission of toxic and hazardous materials, green procurement, green transportation, green packaging, environmental cooperation, labeling the products as 'environment friendly'.	Low rate of wastes Low levels of toxic and dangerous emissions Use of recyclable pallets to deliver material

the received responses, and running ranking tests in descriptive statistics, final agreement is reached on the final characteristics (criteria). The initially identified requirements together with (technical characteristics) and the selected criteria are tabulated in Table 3.

The degree of relative importance of the technical characteristics of the suppliers, in contrast to the L.A.R.G. logistics requirements, is calculated through the H.O.Q. and is based on the integration of expert judgment analyses i. The calculation of the relative importance of the supplier's technical characteristics (Table 4) is calculated through the following equation:

$$w_i = \sum\nolimits_{j=1}^{g} w_j \cdot Rank_{\;i}$$

where, $Rank_i$ is the importance rate of the characteristic and W_j is the logistics need's jth weight.

As mentioned, first, the K index must be calculated according to the related formulas to calculate l_{ij}. In the functions of losses, the amount of loss shall be determined in accordance with any criterion or technical characteristic (in terms of increase, decrease or being fixed its utility). The maximum loss is considered as 100 (as 100%). The process of calculating losses is run for all technical characteristics in order to establish coherence among the criteria (Table 5). The final score of the loss will be calculated by multiplying the weight of each characteristic at the loss value for the discrepancies in the estimated performance of each supplier. Among the suppliers, the option that has the lowest average loss of all technical characteristics is ranked the highest. The final calculations of the estimated weighted loss mean for the four

Table 4. The relative importance degrees derived from H.O.Q. matrix for the technical characteristics of the L.A.R.G. supplier.

Index		Sub index	Normalised weighted value
Lean	C_1	Delivery reliability	0.0464
	C_2	Timely production	0.0649
	C_3	Matching products with specifications	0.06265
	C_4	High quality of parts	0.06266
	C_5	Competitive price	0.05803
Agile	C_6	Production based on order	0.04407
	C_7	Response to urgent orders	0.0487
	C_8	Customer satisfaction	0.07426
	C_9	The ability to change the volume of production	0.06029
	C_{10}	Product customization speed	0.06032
Resilience	C_{11}	Carrying out obligations towards material supply contracts	0.06497
	C_{12}	Payment method	0.03016
	C_{13}	Technical cooperation's	0.04641
	C_{14}	Transparency of supply conditions	0.03729
	C_{15}	Construction time consistent with the supply chain	0.06265
Green	C_{16}	Low rate of wastes	0.06959
	C_{17}	Low levels of toxic and dangerous emissions	0.04405
	C_{18}	Use of recyclable pallets to deliver materials	0.0626
sum			**1**

Table 5. Target values and technical specifications' limits of the L.A.R.G. supplier.

Technical specifications of LARG supplier		Target value	Specifications' limits	Acceptance deviation value	*K* value	Loss function $l_{ij} = k_i(x_i - x_{ij})^2$
lean	C_1	100	80–100	20	0.25	$l_{ij} = 0.25(x_i - x_{ij})^2$
	C_2	100	95–100	5	4	$l_{ij} = 4(x_i - x_{ij})^2$
	C_3	100	95–100	5	4	$l_{ij} = 4(x_i - x_{ij})^2$
	C_4	100	95–100	5	4	$l_{ij} = 4(x_i - x_{ij})^2$
	C_5	100	80–100	20	0.25	$l_{ij} = 0.25(x_i - x_{ij})^2$
Agile	C_6	100	55–100	45	0.05	$l_{ij} = 0.05(x_i - x_{ij})^2$
	C_7	100	80–100	20	0.25	$l_{ij} = 0.25(x_i - x_{ij})^2$
	C_8	100	95–100	5	4	$l_{ij} = 4(x_i - x_{ij})^2$
	C_9	100	80–100	20	0.25	$l_{ij} = 0.25(x_i - x_{ij})^2$
	C_{10}	100	80–100	20	0.25	$l_{ij} = 0.25(x_i - x_{ij})^2$
Resilience	C_{11}	100	95–100	5	4	$l_{ij} = 4(x_i - x_{ij})^2$
	C_{12}	100	55–100	45	0.05	$l_{ij} = 0.05(x_i - x_{ij})^2$
	C_{13}	100	80–100	20	0.025	$l_{ij} = 0.025(x_i - x_{ij})^2$
	C_{14}	100	55–100	45	0.05	$l_{ij} = 0.05(x_i - x_{ij})^2$
	C_{15}	100	95–100	5	4	$l_{ij} = 4(x_i - x_{ij})^2$
Green	C_{16}	100	95–100	5	4	$l_{ij} = 4(x_i - x_{ij})^2$
	C_{17}	100	45	55–100	0.05	$l_{ij} = 0.05(x_i - x_{ij})^2$
	C_{18}	4	5	95–100	100	$l_{ij} = 100(x_i - x_{ij})^2$

suppliers surveyed in the case study of research are expressed in Table 6. The ranking of the four mentioned suppliers are tabulated in Table 7.

The results obtained based on estimating the deviation in the performance of each supplier from the set target value in each one of the L.A.R.G. logistics criteria are bar charted in Figure 2.

5. Sensitivity analysis

In this section, a sensitivity analysis was conducted to analyse the impact of different conditions on suppliers' ranking. In this regard, 13 scenarios have been investigated

Table 6. Weighted loss in each of the technical characteristics.

Characteristics of the LARG supplier		Normalised weighted mean	Supplier's loss rate A	B	C	D
lean	Delivery reliability	0.0464	6.25	100	6.25	25
	Timely production	0.0649	400	3600	400	900
	Matching products with specifications	0.06265	400	2500	2500	1600
	High quality of parts	0.06266	100	2500	1600	1600
	competitive price	0.05803	0	306.25	56.25	56.25
		total	**57.576**	**569.326**	**286.395**	**263.330**
Agile	Production based on order	0.04407	1.25	45	11.25	20
	Response to urgent orders	0.0487	6.25	400	156.25	56.25
	Customer satisfaction	0.07426	400	3600	400	900
	The ability to change the volume of production	0.06029	56.25	400	25	156.25
	Product customisation speed	0.06032	100	225	56.25	25
		Total	**39.486**	**326.487**	**42.709**	**94.955**
Resilience	Carrying out obligations towards material supply contracts	0.06497	400	6400	100	900
	Payment method	0.03016	1.25	101.25	5	20
	Technical cooperation's	0.04641	25	306.25	25	56.25
	Transparency of supply conditions	0.03729	11.25	61.25	5	20
	Construction time consistent with the supply chain	0.06265	100	3600	0	3600
	Low rate of wastes	total	**33.870**	**660.898**	**7.994**	**278.972**
Green	Low levels of toxic and dangerous emissions	0.06959	400	10000	900	4900
	Use of recyclable pallets to deliver materials	0.04405	31.25	5	5	5
	Carrying out obligations towards material supply contracts	0.0626	400	400	400	400
Sum of the loss		Total	**54.252**	**721.160**	**87.891**	**366.251**
The Taguchi weighted loss amount of			**185.184**	**227.871**	**424.989**	**1012.508**

Table 7. Suppliers ranking based on the additive weighted losses.

Supplier	A	B	C	D
The value of the normalised weighted loss	0.0475	0.5840	0.1090	0.2595
Rank	**1**	**4**	**2**	**3**

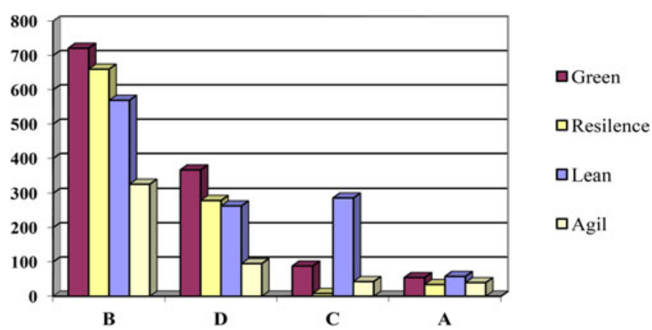
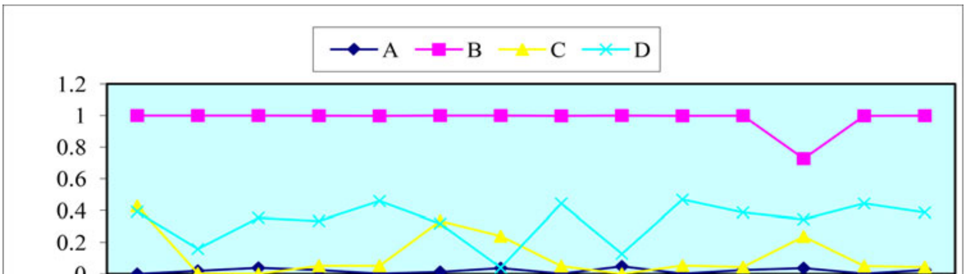


Figure 2. Estimating the weighted loss of each supplier in four approaches.

and the results compared with the supplier rankings that based on T.O.P.S.I.S. method. T.O.P.S.I.S. is a well-known M.C.D.M. technique that chooses alternatives that simultaneously have shortest distance from positive ideal solution and farthest distance from a negative-ideal solution. Also in the literature of decision theory refer to T.O.P.S.I.S. as a valid method which its ranking solutions has little sensitivity to parameters changes of the decision matrix. Here the T.O.P.S.I.S. procedure followed

Table 8. Results of sensitivity analysis for different scenarios.

Scenarios		Criteria (Aggregated sub-criteria)	Suppliers ranking (respectively)	
			Taguchi	T.O.P.S.I.S.
Se.1	Current case	C_1, C_2, ….. ,C_{18}	B≫D≫C≫A	B≫D≫C≫A
Se.2	(Lean criteria only)	C_1, C_2, C_3, C_4, C_5	B≫C≫D≫A	B≫C≫D≫A
Se.3	(Agile criteria only)	C_6, C_7, C_8, C_9, C_{10}	B≫D≫C≫A	B≫D≫C≫A
Se.4	(Resilience criteria only)	C_{11}, C_{12}, C_{13}, C_{14}, C_{15}	B≫D≫A≫C	B≫D≫A≫C
Se.5	(Green criteria only)	C_{16}, C_{17}, C_{18}	B≫D≫C≫A	B≫D≫C≫A
Se.6	Lean & Agile	C_1, C_2, ….. , C_{10}	B≫D≫C≫A	B≫C≫D≫A
Se.7	Lean & Resilience	C_1,.. , C_5 C_{11}, …, C_{15}	B≫D≫C≫A	B≫D≫C≫A
Se.8	Lean & Green	C_1,.. , C_5 C_{16}, C_{17}, C_{18}	B≫D≫C≫A	B≫D≫C≫A
Se.9	Agile & Resilience	C_6,.. , C_{10} C_{11}, … , C_{15}	B≫D≫A≫C	B≫D≫A≫C
Se.10	Agile & Green	C_6,.. , C_{10} C_{16}, C_{17}, C_{18}	B≫D≫C≫A	B≫D≫C≫A
Se.11	Resilience & Green	C_{11}, … ,C_{15}, C_{16}, C_{17},C_{18}	B≫D≫C≫A	B≫D≫C≫A
Se.12	Lean & Agile & Resilience	C_1, C_2, ….. , C_{15}	B≫D≫C≫A	B≫D≫C≫A
Se.13	Lean & Agile & Green	C_1,.. , C_{10}, C_{16}, C_{17}, C_{18}	B≫D≫C≫A	B≫D≫C≫A
Se.14	Agile & Resilience & Green	C_6,.. , C_{10}, C_{11}, … , C_{18}	B≫D≫C≫A	B≫D≫C≫A



	curent	se.1	se.2	se.3	se.4	se.5	se.6	se.7	se.8	se.9	se.10	se.11	se.12	se.13
A	0	0.02	0.039	0.025	0.002	0.013	0.037	0.002	0.048	0.002	0.025	0.037	0.002	0.025
B	1	1	1	0.999	0.998	1	1	0.998	1	0.998	0.999	0.727	0.998	0.999
C	0.428	0.0031	0	0.052	0.052	0.334	0.239	0.05	0	0.053	0.044	0.237	0.05	0.044
D	0.392	0.158	0.354	0.334	0.459	0.318	0.0393	0.443	0.127	0.468	0.387	0.344	0.443	0.387

Figure 3. Results of sensitivity analysis by T.O.P.S.I.S. method.

by applying the Table 6 as a weighted normalised decision matrix which is needed in this method. Then positive and negative ideal solutions are determined. Calculating a separation measure for each alternative is the next step. The procedure ends by calculating the relative closeness coefficient (c_i). The suppliers A to D are ranked according to the descending order of the closeness coefficient. Table 8 shows the details of considered scenarios and the differences between the T.O.P.S.I.S. and Taguchi methods in ranking of suppliers are highlighted in this table. In general, as it can be seen from this table, the Taguchi method seems to be less sensitive for the changes appeared in different scenarios unless 6 Scenario, only In this case, the T.O.P.S.I.S. and Taguchi methods in ranking of suppliers distinguishes the variation between alternatives. In the other cases the T.O.P.S.I.S. method achieved the same results, this capability of the Taguchi method can assist D.M.s more when the nature of criteria is very subjective, and judgment is not straightforward. A graphical representation of the T.O.P.S.I.S. results base on the relative closeness coefficient (c_i) depicted in Figure 3.

6. Conclusion and discussion

Supplier selection is one of the critical decision-making activities to obtain competitive advantage and achieve supply chain objectives. To achieve this business goal, the D.M.s should apply the best method and apply accurate criteria to analyse and solve supplier selection problems. This article proposes a novel integration technique using H.O.Q., M.O.P.A. and Taguchi loss function to evaluate and select the best supplier. An important part of the operation strategies includes appropriate strategies to meet the needed requirements and select a superior supplier according to the considered industry needs. The method presented in this study, due to adopting the Q.F.D. model, is able to consider firms' strategies in the realm of logistics services referred to as needs. Applying of the Taguchi loss function empowers the decision-makers to select the quantitative and qualitative criteria of the inbound logistics' services and to assess the suppliers' responsibility. The L.A.R.G. paradigms is an original contribution in this article, since there is no theoretical or practical research studies were done on these four paradigms. The flexibility of evaluating any number of suppliers and select the best of them is an added value to this work, which contributes also to improve the supply chain performance.

In this article, a model was designed and implemented to investigate the following points:

- An extensive overview on the LARG paradigms and the performance indicators introduced in the system.
- An evaluation and selection of the right supplier for an organisation. This should not only meet customer requirements and bring profit to the firm, but also help in fulfilling various criteria and technical specifications and hence increasing the SC performance.
- A comparative study for each one, two, three, and four paradigms. This study can be regarded as a general framework for applying any combination of paradigms for evaluating and improving supply chain performance.

A sensitivity analysis shows that different conditions have less impact on suppliers' ranking and the proposed model is valid and applicable.

This proposed model can be modified through various M.A.D.M. techniques and determine the supplier's Rank in fuzzy space. In this study, it is assumed that each selected supplier can meet all logistic needs, while in practice; it is possible that this assumption would encounter difficulties due to various risks, like problems with the transfer of fund of contract, etc. Therefore, developing this pattern must have preference in order to consider the circumstances and these types of constraints and determine the optimal purchase volume from each supplier in terms of their performance estimation. This objective can be achieved by applying multi-objective mathematical models or goal programming with definite, fuzzy, or deterministic parameters.

Disclosure statement

No potential conflict of interest was reported by the authors.

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