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Supplier selection in closed loop supply chain by an integrated simulation-Taguchi-DEA approach

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Abstract

Purpose – Reverse logistics refer to processes related to the reuse of products. The role of suppliers' performance is crucial in achieving quality, cost, service and delivery aims of a supply chain. The selection of suppliers is regarded as one of the critical issues encountered by purchasing and operations managers in a supply chain to enhance organization's global marketplace competitiveness. Most of the supply chain models are rather complex problems. Consequently, it is impossible to propose systematic models to handle them. Therefore, in this paper a new integrated approach based on experimental design and computer simulation is proposed for supplier selection. The paper aims to discuss these issues.

Design/methodology/approach – In this study, a simulation approach is implemented to determine certain equivalent of parameters values in a CLSC network design which cannot be computed through mathematical model. Suppliers' order quantities are investigated by Taguchi method for planning time horizon. Moreover, data envelopment analysis (DEA) is applied to assess suppliers based on quality, cost, delivery time, production capabilities, services and technology.

Findings – In the numerical example, there are three suppliers for different regions. Purchase value of each supplier is measured in three years successively. According to the proposed method, the authors find the minimum level of costs together with the maximum number of high-quality products.

Practical implications – The objective functions of model are minimizing the costs and maximizing number of high-quality products. The integrated approach introduced in this paper enables managers to select their suppliers effectively in their real system.

Originality/value – Most supply chain models are complex and the identification of proper and optimal solutions in complex real-world systems often requires the solution of multi-objective problems involving multiple stochastic variables. Therefore, the paper introduces a new integrated approach for supplier selection in closed loop supply chain. To the best of the authors knowledge, this is the first study that integrates DEA, computer simulation and Taguchi method for supplier selection in closed loop supply chains.

Keywords Data envelopment analysis (DEA), Computer simulation, Supplier selection, Taguchi method, Closed loop supply chain

Paper type Research paper

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1. Introduction

Excessive demand for production resources and increasing awareness of negative effects of manufactured products on environment have attracted the attention of the researchers to reverse supply chain logistics (De Brito and Dekker, 2004). Reverse logistic is defined as "the process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal" (De Brito and Dekker, 2004; Rogers and Tibben-Lembke, 1999; Schultmann *et al.*, 2006). Reverse logistic does not treat only reverse flows from customers to manufacturer, but also considers forward flows of supply chain network, resulting in a new concept which is referred to as closed loop supply chain (CLSC; Fleischmann *et al.*, 2004; Rubio *et al.*, 2008).

Various forms of supply chain configuration could be considered based on levels of chain such as supplier, producer, distributer, collection centers and recycling centers (Graves and Willems, 2003; Marien, 1998; Savaskan *et al.*, 2004). In older studies, reverse side of supply chain has been regarded as a separate part (Spekman *et al.*, 1998). As a result, solutions are obtained through optimizing each subproblem, i.e. forward supply chain and reverse supply chain. This approach does not guarantee a global optimal solution. However, recently forward and reverse chains are considered together to avoid sub-optimality which leads to the concept of closed loop supply chain (Hammond and Beullens, 2007).

Supply chain management considers other optimization criteria rather than cost minimization. This implies for implementation of other techniques such as analytic hierarchy process (AHP; Liu and Hai, 2005), analytic network process (Gencer and Gürpinar, 2007), case-base reasoning (Choy and Lee, 2002), data envelopment analysis (DEA), fuzzy theory (Amid *et al.*, 2006), genetics algorithm (Yeh and Chuang, 2011), mathematical programming (Amid *et al.*, 2006) and different combinations of them (De Boer *et al.*, 2001).

The evaluation of correct trades-offs between conflicting factors in supply chain management, such as customers' satisfaction, inventory reduction and fill rates, sales loss, inventory costs, transportation cost, internal costs and resources management are (among others) the most important responsibilities of a competent supply chain manager. Therefore, supply chains have to be regarded as complex systems; a wide range of factors usually affects the behavior of complex systems. The ways in which such factors interact and the stochastic nature of their evolution over the time increase the complexity of many real-world supply chains up to critical levels, where the use of ad hoc methodologies, techniques, applications and tools is the only way to tackle problems and succeed in identifying proper and optimal solutions (Castilla and Longo, 2010).

To this end, simulation has been widely recognized as the best and most suitable methodology for investigation and problem-solving in real-world complex systems in order to choose correctly, understand why, diagnose problems, explore possibilities, train personnel and managers, find optimal solutions (Banks, 1998).

In this paper, we implement a simulation computer approach for determining the certain equivalent of parameters values in a CLSC network design problem. The simulation computer is used because the problem is complex and cannot be solved through mathematical model. Taguchi method is used to investigate the suppliers' order quantities for planning time horizon. The Taguchi method is one such tool for conducting experiments using a statistical approach to understand the significance of independent factors and levels. The main advantage of Taguchi method is that the number of experiments conducted in most of the cases is lesser than that of any other experiment using a statistical approach. Moreover, DEA is applied to assess and evaluate the suppliers according to quality, cost, delivery time, production capabilities, services and technology. DEA is a linear programming methodology to measure the efficiency of multiple decision-making units (DMUs; Azadeh *et al.*, 2015a, b). A key advantage of DEA over other multi-criteria decision-making approaches is that it more easily accommodates both multiple inputs and multiple outputs. As a result, it is particularly useful for analysis of multispecies fisheries, because prior aggregation of the outputs is not necessary.

The rest of this paper is organized as follows. The some relevant studies have been reviewed in Section 2. The problem description is presented in Section 3. In Section 4, the objective functions as well as the proposed model are presented. The numerical example is presented in Section 5. Finally, the paper is concluded in Section 6.

2. Literature review

One of the oldest methods used in this field is DEA which considers different criteria to determine the best supplier like what (Liu *et al.*, 2000) have done in their study. This method has been developed to cope with increased numbers of criteria. Narasimhan *et al.* (2001), have grouped suppliers into four categories by defining eleven criteria which includes five output criteria and six inputs. Because of the importance of issue, in several surveys, designing of the supply chain network has been done in different phases. In the first and second phase, supplier determination is applied utilizing one of the methods mentioned above. Talluri and Baker (2002) designed supply chain network in three phases; first, score of each supplier has been determined, second, optimal number of suppliers has been specified. Amin and Zhang (2012), used AHP method initially to identify the score of each supplier and then selected suppliers in an integrated model.

Ross *et al.* (2006) evaluated efficiency of suppliers while considering customer and supplier performance share using DEA method. Therefore, three sensitivity analyses were conducted. Talluri *et al.* (2006) evaluated supplier efficiency in terms of probable efficiency indices using DEA and chance constraint method. They compared their model with a decisive model to demonstrate the efficiency of it. Likewise, Ng (2008) developed a linear programming model to select supplier while he intended to maximize supplier score. In his work, similar to AHP method, experts were asked to determine the relative weights. Choy and Lee (2002) addressed three groups of criteria for a case study and developed a general model to determine supplier.

In the context of supply chain management, Azadi *et al.* (2015) proposed a novel fuzzy DEA model to evaluate and assess the efficiency of suppliers. Their model indicated the amount of effectiveness and productivity in ambiguous environment with different levels of α-cut. Kannan *et al.* (2014) proposed an approach using Fuzzy TOPSIS to select green suppliers and rank them for a Brazilian electronics corporation. The proposed approach was built considering factors of green supply chain management.

In proposed methods so far, one can see DEA approach and mathematical programming are placed in the subsequent level. The most common criteria used in the investigated models are quality, delivery, cost, production capabilities, services and technology. Different features of quality have been examined in these surveys such as: accepted fragments per million, sustained improvement programs, six sigma programs or TQM (Kumar *et al.*, 2008), corrective and predictive operational systems (Kleijnen and Smits, 2003), archiving, monitoring and control, net passed fragments, faultless deliveries from the supplier (Gunasekaran *et al.*, 2004), existence of the ISO quality system (Sroufe and Curkovic, 2008), number of quality section staff, control process, qualitative reporting and information (Guide *et al.*, 2003).

Despite shared similarities among considered criteria in the mentioned models to select the supplier, none has taken into account the influence of business goals and needs of company associates in supplier selection. In fact, selection of these criteria and consequently of supplier has been done without recognition of other members of the chain. Integration of AHP and quality function deployment (QFD) methods can assist us to achieve this goal. What QFD can do in the context of supplier selection is to determine the weight of each criteria which are specified by associates of the chain (Sohn and Choi, 2001). Characteristics of this study and other studies are summarized in Table I.

3. Problem description

In this study, a closed loop supply chain has been considered consisting of four levels of supplier, producer, distributer/collector and consumer. Costs which have been taken into account in the chain include transportation, production, raw material and ultimate product preservation, shortage costs, as well as costs related to reverse current activities, raw material purchasing, making contracts with the suppliers and their cancellation (Beamon, 1999). Supply chain incomes include product selling to customers, selling of returned unrecyclable or irreparable products to the outside of the chain (Handfield and Nichols, 1999). Every supplier has a consistency in its production which causes the raw material used for the production of the final product which have different levels of quality (Christopher, 2012). In addition, the supplier with respect to technology, consistency of

Studies	Criteria	Solution approach	Remark
Azadeh *et al.* (2016)	Quality; delivery; cost; production capabilities; services and technology performance	Integrated simulation-Taguchi-DEA	Considering two new factor for supplier selection problem including influence of business goals and needs of company associates for maximizing the benefit from supply chain and increasing the number of high-quality productions
Azadi *et al.* (2015)	Economic; social; environmental	Fuzzy DEA	Evaluating efficiency and effectiveness of suppliers in an ambiguous environment
Kannan *et al.* (2014)	Commitment of senior management; product design; satisfying legal environmental requirements	Fuzzy TOPSIS	Selecting green suppliers for a Brazilian electronics company
Amin and Zhang (2012)	Cost; quality; service; capacity	Fuzzy multi-objective linear model	Handling the imprecision and vagueness of data and the varying importance of factors
Choy and Lee (2002)	Technical capability; quality assessment; organization profile	Case-based reasoning technique	Proposing an intelligent generic supplier management tool for outsourcing to suppliers
Yeh and Chuang (2011)	Cost; time; quality of product; green factors	Multi-objective genetic algorithm	Developing an optimum mathematical planning model for green supplier selection
Kahraman *et al.* (2003)	Product performance; service performance; cost; financial; technical; support resource	Fuzzy AHP	Selecting the best supplier in an ambiguous environment

Table I. The characteristics of this study and other study the production process and the quality of the raw materials produces the final product which has different levels (Östlin *et al.*, 2008; Wang *et al.*, 2004).

This study aims to determine amount of order made to each supplier in planning period of time to maximize gained benefit as well as number of high-quality products in supply chain. The raw material bought from supplier, once purchased is delivered to raw material storehouse. Then, the producer produces the final products and sends them to the distributer which could be regarded as a storehouse as well. Each final product follows a life distribution according to its quality level. The consumer purchases the product with a fixed price from the distributer and after the expiration of the product, returns it to distribution centers which also play the role of collectors in which the product is purchased from the customer. Thus, if the lifetime of product is more than a certain level (if the customer is certain about the endurance of the purchased product), the product will attract more customers. This issue results in an increased number of customers in future dealings, and the customer, after returning the consumed product, would likely buy another product from the same distributer. If the product's lifetime is less than a certain amount, not only the customer would be lost but also the number of customers in subsequent periods would decrease as many as an uncertain value. Decreased value relate to customers who would be added to the current customer population. If the products lifetime falls in the intermediate span of the product's distributional lifetime, no changes in the number of customers would happen for subsequent periods and would purchase the product with a specific probability; otherwise, would purchase other products from other companies and would be regarded as a missed customer.

After being returned by the customer, the product is classified and based on its condition, three types of activities could be conducted on it (Guide *et al.*, 2003). First, if the quality of the product is not so poor, it can be repaired in the collection place with low time and cost, and be returned to the distribution center and consequently join to the forward flow; those products which have a lower quality are recycled to their raw materials and kept in raw material storehouses. Recycling procedures are done in the collection place to increase transportability of the materials to the storehouse (Nagurney and Toyasaki, 2005). On the other hand, those with the lowest quality are sold to other industries with a fixed price. If the returned product is high quality or is not, it is repaired with a certain probability; otherwise, depending on the preliminary quality of the consumed product and with a specific probability is either recycled or sold out (Fisher and Hammond, 1994).

Parameters influencing on the benefit of the mentioned supply chain include: customer's type of consumption, which is stated in terms of the product's consumption time, quality of preliminary material produced by each supplier, quality of final products of factory and the transportation time between different levels of supply chain (McLaren *et al.*, 2002). Figure 1 depicts a schematic representation of assumed supply chain.

4. Objective functions and the proposed model

The experimental variables in this experiment are as follows:

- cash flows of the chain which include transportation, production, preservation of raw and produced materials cost, shortage cost, cost related to reverse current activities, and cost of making contracts with the supplier and their cancellation; and
- number of productions with poor quality.

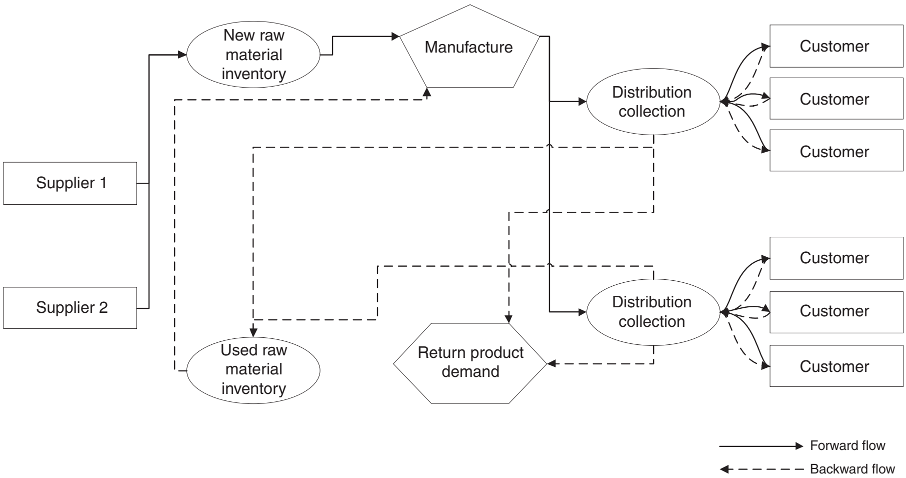

Figure 1. Schematic representation of closed loop supply chain

4.1 Turbulence parameters

- type of customer consumption stated in terms of product's consumption time;
- quality of preliminary materials produced by each supplier;
- quality of the final product produced in the factory; and
- transportation time between different levels of supply chain.

4.2 Control variable

- order quantity of each supplier in a three-year period of programming.

4.3 Proposed mathematical model

Indices of model are as follows:

i, this index indicates supplier; j, this index indicates period.

In this model the following parameters have been utilized:

C_i, capacity of the ith supplier per year; K_i, purchasing cost of preliminary material from ith suppler for each unit of preliminary material required for each product; L, cancellation cost of partnership with each supplier; C, cost of making a contract with a supplier for the first time; h_1, preservation cost of each unit of preliminary material per month; h_2, preservation cost of any unit of final product per month; O, shortage cost imposed on the chain for each customer; S, sales price of final product for each customer; S', sales price of consumed products to outside of chain; M_1, production cost of final product unit; M_{21}, repair cost for unit of consumed product; M_{22}, recycling costs of consumed product unit; Tr_1, transportation cost of preliminary material for producing a unit of final product; Tr_2, transportation cost for each unit of final product.

- Decision variables in this model are as follows:
  X_{ij}, number of purchased preliminary material from supplier i in the period j

- Output variables of the model are:

y_{1j}, number of repaired products in the jth period; y_{2j}, number of output products from chain (products sold to other industries); y_{3j}, number of recycled products in the jth period; I_j, number of unsold products at the end of each period; P_{1j}, number of high-quality products in the jth period; P_{2j}, number of poor-quality products in the jth period; b_j, number of shortages in the jth period; X'_j, number of produced products in the jth period; Z_{ij}, supply by the ith supplier in the jth period (this variable is binary).

According to the mentioned variable and parameters, the closed loop supply chain model is as follows (Expression (1)):

$$\sum_i \sum_j X_{ij} \times (Tr_1 + K_i) + \sum_j O \times b_j + \sum_j X_j (M_1 + Tr_2)$$
$$+ \sum_j y_{1j} \times M_{22} + \sum_j y_{3j} \times (Tr_2 + M_{21}) + \sum_j \frac{h_2 \times \left(X_j - X'_j\right)}{2}$$
$$+ \sum_i \sum_j \left(Z_{ij} - Z_{i,j-1}\right) \times L + \sum_i \sum_j Z_{ij} \times C \quad (1)$$

In Expression (1), the first part indicates costs related to purchase and transportation of preliminary material from the supplier. Second part shows shortage costs in each period. Third part depicts production and transportation costs to distribution centers. Fourth part represents repairing costs of consumed products in reverse process. Fifth part shows storing cost in chain for each period. Sixth part is the cost related to disconnection of each supplier. The last part indicates the cost of first connection with each supplier. The revenue from each supply chain is represented as follows (Expression (2)):

$$\sum_j S \times \left(X'_j - I_j\right) + \sum_j y_{2j} \times S' \quad (2)$$

In Expression (2), the first part is related to product sales in each period and the second part is related to the consumed product sales in each period to centers outside the supply chain. According to the specified costs and revenues in the intended supply chain, the first objective function is shown by Expression (3):

$$W_1 = \sum_j S \times \left(X'_j - I\right) + \sum_j y_{2j} \times S' - \sum_i \sum_j X_{ij} \times (Tr_1 + K_i) - \sum_j O \times b_j$$
$$- \sum_j X_j (M_1 + Tr_2) - \sum_j y_{1j} \times M_{22} - \sum_j y_{3j} \times (Tr_2 + M_{21}) - \sum_j \frac{h_2 \times \left(X_j - X'_j\right)}{2}$$
$$- \sum_i \sum_j \left(Z_{ij} - Z_{i,j-1}\right) \times L - \sum_i \sum_j Z_{ij} \times C \quad (3)$$

As mentioned at the beginning, the second objective function in this survey is the number of high-quality products which represents how responsible the chain is toward its customers. This objective function is shown as below:

$$W_2 = \sum_j P_{1j} \tag{4}$$

Constraints of the model are as follows:

$$\sum_j X'_j = \sum_j \left(y_{1j}+y_{2j}+y_{3j}\right) \tag{5}$$

$$Z_{ij} \leqslant C_i \times X_{ij} \quad \forall i,\, j \tag{6}$$

$$X_j = P_{1j}+P_{2j} \quad \forall j \tag{7}$$

$$I_j+b_j+X'_j = X_j \quad \forall j \tag{8}$$

$$Z_{ij} = 0,1 \quad \forall i,\, j \tag{9}$$

$$X_{ij}, X_j, X'_j, y_{1j}, y_{2j}, y_{3j}, I_j, b_j \geqslant 0 \quad \forall i,\, j \tag{10}$$

In Equation (5), balance between number of sold products and number of products in the reverse flow which have been under operation in that period are shown. In Expression (6), we intended to determine Z_{ij} value in case the preliminary material is not purchased from the supplier, the costs of which are taken into account in the objective function. In Equation (7), the relationship between high-quality and low-quality products in each period and the number of produced products in that period are balanced, and Equation (8) is representative of equilibrium flows for each period.

Given that the assumed model has two experimental variables, therefore, a cumulative function is needed to convert them to a certain equivalent in order to do calculations on them. In this survey, two methods are used for integrating the experimental variables:

(1) Weighted mean: since the two experimental variables should be maximized, this method could be used, but at the beginning the scale of these variables should be standardized. To do so, the following equation is used to change experimental variables scale for the range [0,1]:

$$y_{code} = \left(\frac{y_{uncode}-L}{U-L}\right) \tag{11}$$

(2) Coefficient of experimental variables: as mentioned, experimental variables should be maximized, thus in this method after conversion of the scale of experimental variables, they are multiplied by each other and a final value is achieved for each experiment.

In Figure 2, the roadmap of this study is illustrated. According to the roadmap the process of the proposed approach is described in four steps. Each step is fully explained in the previous sections.

5. Numerical example

In this example there are three suppliers and the purchase values are determined in three years in a row. In this chain, there are two suppliers which have been dedicated to two regions. To determine the decision variables, the stimulation was done using Arena version 11. Because of this, some parameters which could not be modeled, are not presentable in the primary model which was mentioned in the previous section. Thus, all parameters that are used in the numerical example are shown in Table II.

In this model, number of customers who are not satisfied with their purchase in the range [1,5], and those who are satisfied between [2,10] are randomly removed from the group of potential customers of the system. To determine the type of returning products, high-quality products with 30 percent of probability and poor-quality products with 15 percent of probability are repaired. If the quality of the product is high and low with an 80 and 40 percent of probability, respectively, the rest products are recycled. The rest of them are sold to the outside of the system and it is assumed that there is always a customer for these products.
The suppliers would produce high and low-quality products depending on their technology as the distribution of them is depicted in Table III.

In Figure 3, a view of the simulated part of the model is represented. To determine the value of decision variables, an experimental design method has been applied.

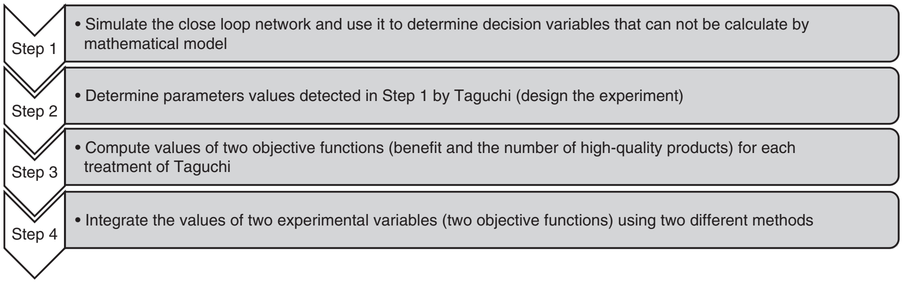

Figure 2. The stages of this study

Table II. Parameters that are used in the numerical example

Parameter	Amount	Parameter	Amount
C_i	800,600,500 (number per year)	S'	30 (1,000 units)
K_i	60,50,40 (1,000 units)	M_1	50 (1,000 units)
C	3,000 (1,000 units)	M_{21}	30 (1,000 units)
h_1	5 (1,000 units per month)	M_{22}	45 (1,000 units)
h_2	5 (1,000 units per month)	Tr_1	1,088 (1,000 units)
O	50 (1,000 units)	Tr_2	12 (1,000 units)
S	400 (1,000 units)	L	10,000 (1,000 units)

Table III. Specifications of the suppliers

	First supplier	Second supplier	Third supplier
Quality of productions	DISC(0.75, 1, 1, 2)	DISC(0.85, 1, 1, 2)	DISC(0.95, 1, 1, 2)
Shipment time interval	UNIF(20, 30)	UNIF(20, 30)	UNIF(20, 30)
Transportation time to factory (days)	NORM(1, 0.5)	NORM(1, 0.2)	NORM(1.5, 1)

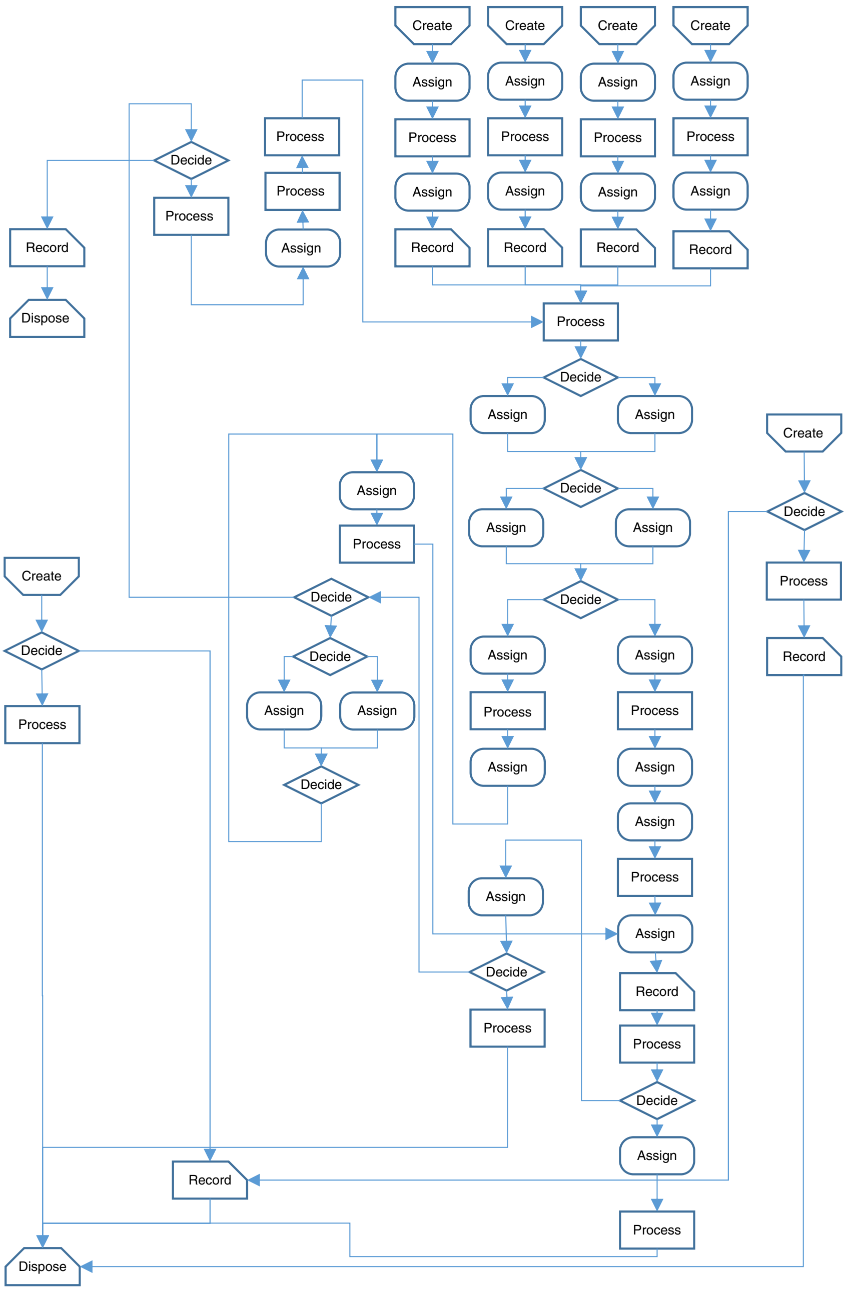

Figure 3.
Simulated model of closed loop supply chain by Arena

This experimental design is Taguchi method used to design experiment (Taguchi, 1987). The results of this experimental design are represented in Table IV.

In the next step, obtained functions are integrated. In Table V, using three aforementioned methods at the beginning of the report, these values are calculated. It is

Table IV.
Design of experiment using Taguchi method

Treatment	x11	x12	x13	x21	x22	x23	x31	x32	x33	Benefit	Good Prod
1	−1	−1	−1	−1	−1	−1	−1	−1	−1	−2,2850	0
2	−1	−1	−1	−1	−1	−1	0	0	−1	49,771.4	232
3	0	0	−1	0	0	−1	0	0	−1	61,585	786
4	0	0	−1	0	0	−1	1	1	−1	26,284.383	1,018
5	1	1	−1	1	1	−1	1	1	−1	−129,188.8	1,510
6	1	1	−1	1	1	−1	−1	−1	−1	−13,157.47	1,063
7	−1	−1	−1	0	1	−1	−1	0	1	109,075.25	294
8	0	0	−1	1	−1	−1	0	1	1	7,857.15	1,019
9	1	1	−1	−1	0	−1	1	−1	1	18,342.364	1,065
10	−1	−1	−1	1	0	1	−1	1	−1	86,865.673	543
11	0	0	−1	−1	1	1	0	−1	−1	95,788.91	559
12	1	1	−1	0	−1	1	1	0	−1	−29,507.05	1,584
13	−1	0	−1	1	−1	1	1	0	1	36,362.403	957
14	−1	0	−1	1	0	1	−1	−1	1	90,085.507	543
15	0	1	−1	−1	0	1	−1	1	1	82,035.363	321
16	0	1	−1	−1	1	1	0	0	1	85,781.157	559
17	1	−1	−1	0	1	1	0	−1	1	5,662.7758	1,063
18	1	−1	−1	0	−1	1	1	1	1	−39,486.55	1,268
19	−1	1	1	0	−1	−1	0	1	−1	65,940.151	541
20	0	−1	1	1	0	−1	1	−1	−1	−15,827.31	1,227
21	1	0	1	−1	1	−1	−1	0	−1	80,199.893	642
22	−1	0	1	−1	1	−1	1	1	1	117,444.96	535
23	−1	0	1	0	1	−1	1	−1	1	108,551.49	675
24	0	1	1	0	−1	−1	−1	−1	1	78,507.816	580
25	0	1	1	1	−1	−1	−1	0	1	33,536.18	786
26	1	−1	1	1	0	−1	0	0	1	−41,467.51	1,303
27	1	−1	1	−1	0	−1	0	1	1	58,486.009	862
28	−1	1	1	1	1	1	0	1	−1	51,203.792	778
29	−1	1	1	−1	0	1	1	0	−1	115,444.96	535
30	0	−1	1	−1	−1	1	1	−1	−1	60,817.468	749
31	0	-1	1	0	1	1	−1	1	−1	91,487.438	580
32	1	0	1	0	0	1	−1	0	−1	35,501.654	865
33	1	0	1	1	−1	1	0	−1	−1	−41,458.98	1,303
34	−1	1	1	0	0	1	0	−1	1	101,853.13	541
35	0	−1	1	1	1	1	1	0	1	−35,971.31	1,227
36	1	0	1	−1	−1	1	−1	1	1	60,129.893	642

Implementation	First metrical method	Second metrical method	Multiplication method of functions	Implementation	First metrical method	Second metrical method	Multiplication method of functions
1	0.301813	0.21558	0	19	0.65628	0.566355	0.270216
2	0.551867	0.436038	0.106276	20	0.554131	0.617128	0.356043
3	0.690321	0.634861	0.383825	21	0.715881	0.627145	0.344097
4	0.63407	0.636529	0.405131	22	0.801326	0.668876	0.337753
5	0.285985	0.476641	0	23	0.802599	0.695038	0.41077
6	0.530648	0.570773	0.315719	24	0.699336	0.604144	0.308354
7	0.731927	0.575835	0.179307	25	0.610712	0.577998	0.327393
8	0.581959	0.599487	0.357464	26	0.495752	0.589138	0.292578
9	0.62043	0.635264	0.402185	27	0.695919	0.652569	0.4141
10	0.71605	0.609408	0.3003	28	0.659342	0.61129	0.359245
11	0.744407	0.632549	0.321917	29	0.795649	0.664822	0.335014
12	0.582918	0.702085	0.404169	30	0.681135	0.621626	0.364286
13	0.65112	0.637705	0.405543	31	0.736175	0.630457	0.327624
14	0.725189	0.615936	0.304775	32	0.631253	0.606919	0.364651
15	0.660295	0.52954	0.173557	33	0.495777	0.589155	0.292607
16	0.716002	0.61226	0.307597	34	0.758209	0.639161	0.319949
17	0.584064	0.608927	0.366929	35	0.496958	0.57629	0.292775
18	0.494746	0.582106	0.291149	36	0.658918	0.586457	0.311115

Table V. Integrative functions using mentioned methods

noteworthy that the metrical method was used twice and each time the used weights have changed as shown in Table VI.

Now, for each method obtained data are analyzed using Taguchi method. The obtained data based on metrical integrative function 1 are presented in Figures 4 and 5.

Since we intend to maximize the integrative function, values of variables are determined so that they maximize the intended equivalent and if a variable has no effect in the obtained mean, its value is determined so that the value of signal rate to disturbance is increased. With this in mind, the adjustments which we determine for the model are presented in Figure 4. Value of obtained integrative function from this adjustment shows the appropriateness of the response.

The diagrams for obtained results of other methods are presented in the Appendix. In Table VII, results are depicted. First result is based on the first metrical integrative function, the second from the second integrative function, and the third has been obtained by considering the multiplied integrative function. As results indicate, it is realized that in the first year, a smaller number of orders are purchased from the suppliers. There are two reasons for this result, the first is that in the first year the number of customers is lower than the other years and the second one is that the disconnection from the supplier bears extra costs. Then, it is more reasonable to buy less in the first year. Also, with the increasing number of customers, new contracts

	Coefficient of the first function (benefits)	Coefficient of the second function (number of high-quality products)
First time	0.8	0.2
Second time	0.5	0.5

Table VI. Coefficients used in metrical method to integrate objective functions

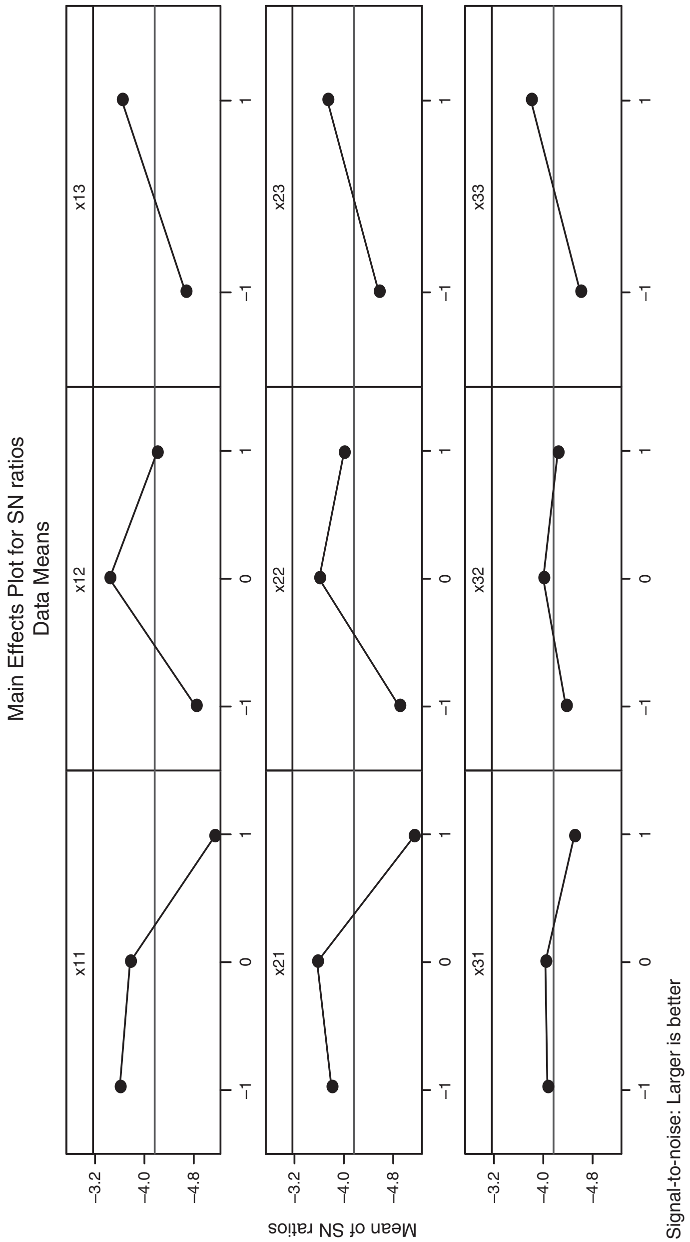

Figure 4.
Diagram of effects of variables on signal rate to disturbance for the first metrical function

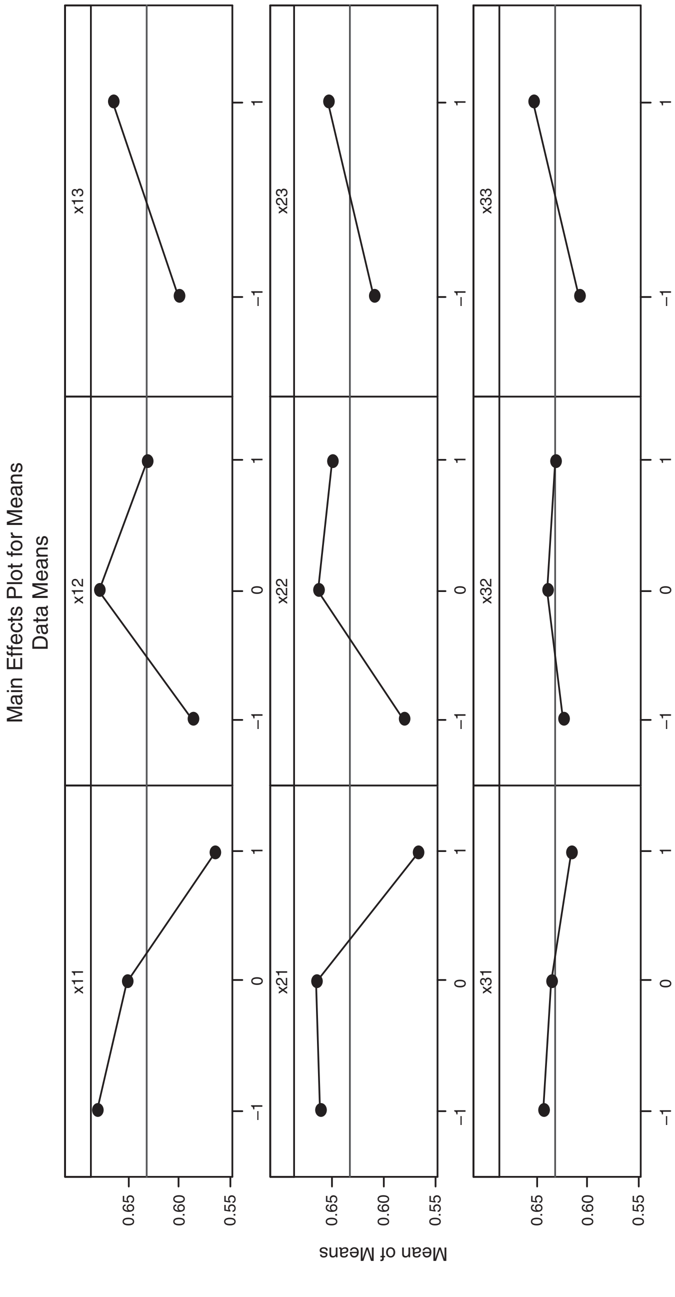

Figure 5.
Diagram of effects of variables on the amount of the first metrical integrative function

Table VII.
The features of this study vs other studies and methods

Study	Feature: Influence of business goals	Needs of company associates	Analysis of parameters (experimental design)	Quantity of order	Benefits of chain	Determining decision variables by stimulation
The proposed approach	✓	✓	✓	✓	✓	✓
Amin and Zhang (2013a)					✓	
Amin and Zhang (2013b)				✓	✓	
Özceylan *et al.* (2014)			✓		✓	
Soleimani *et al.* (2014)			✓		✓	
Ramezani *et al.* (2014)				✓	✓	
Pazhani *et al.* (2013)					✓	
Zhou *et al.* (2013)			✓		✓	
Sharma and Balan (2013)			✓	✓	✓	
Jayaraman (2006)					✓	

must be made with suppliers and more preliminary material must be purchased. As can be seen, in the second response the weight of the second objective function is increased. As a result, the number of high-quality products is increased which satisfies objectives introduced in model as well. Since the multiplied integrative function has calculated considering the same weight for the two functions, the obtained results from this method are almost the same as the results from the second metrical method.

5.1 The implications of this research on theory and practice

In this paper an integrated simulation-Taguchi-DEA approach is proposed in order to determine amount of order made to each supplier in planning period of time to maximize gained benefit together with number of high-quality products in supply chain. In this paper, the simulation computer is used because it is easy to vary the range of input parameter values. In case of a real experiment of supplier selection, the extreme values are limited by the practical constraints. Also, the time and cost required to simulate the experiment is, in many cases, less. We use Taguchi method to investigate the suppliers' order quantities for planning time horizon. Taguchi method emphasizes a mean performance characteristic value close to the target value rather than a value within certain specification limits, thus improving the product quality. It allows for the identification of key parameters that have the most effect on the performance characteristic value so that further experimentation on these parameters can be performed and the parameters that have little effect can be ignored. DEA is a linear programming-based technique for evaluation the relative performance of supplier where the presence of multiple inputs and outputs makes comparisons difficult. Using DEA, not only the manager can calculate the optimal values of its supplier efficiencies but also the sources of inefficiency can be analyzed and quantified for every evaluated supplier. The abovementioned reasons indicate the proposed method can efficiently cope with the supplier selection problem. In Table VII, reader can see the features of this study vs other previous studies and methods.

6. Conclusions

In this study, a closed loop supply chain has been surveyed. Because supply chain models are mainly complex problems, providing systematic models for them is very difficult and requires spending a lot of time. Therefore, approximate methods like experimental design can be used. DOE has been used to obtain suitable responses for systems that systematic equation cannot be determined. In proposed model, the experimental variables are benefits of chain and number of low-quality products. Moreover, control variable is the quantity of order. Also, four turbulence parameters are taken to account: type of customer consumption, quality of raw materials, quality of final product and transportation time.

The objective functions of model seeks to minimize the costs (or to maximize benefits) and to maximize number of high-quality products. To this end, we integrated three tools including simulation, Taguchi method and DEA approach to use efficiently the advantages of them simultaneously. Supplier selection is a multi-criteria problem which includes both quantitative and qualitative factors. In order to select the efficient suppliers it is required to make a tradeoff between these intangible and tangible factors some of which may conflict. Simulations are experimental systems. The complexity of supply chain management can make it closer cousins in complexity to nature itself than to simple analytic models, but with a powerful advantage over the real world: the modeler has complete control of the system. Thus, the advantage that simulation gives to scientific exploration is that the model system is strongly manipulable. Taguchi method for experimental design is straightforward and easy to apply to many engineering situations, making it a powerful yet simple tool. It can be used to quickly narrow down the scope of a research project or to identify problems in a manufacturing process from data already in existence. Using a linear mathematical programing for evaluating supplier's efficiency, capable of handling multiple inputs and outputs and capable of being used with any input-output measurement are three key advantages of the proposed method due to employ DEA method.

In numerical example, three suppliers are considered. Purchase value of these suppliers is measured in three years successively. In the chain, there are two suppliers for two different regions. The decision variables are determined by stimulation approach. Simulation process was performed using Arena version 11. According to results obtained from numerical experiments the smallest numbers of orders are purchased from the suppliers in the first year. Proposed model considers impact of business objectives and needs of company associates in the supplier selection problem for the first time.

6.1 Research limitations

The main limitations of the proposed method are as follows. Our review focusses on the application of decision-making techniques for supplier selection. Other important aspects such as criteria evaluation and in analysis supplier selection processes, were not involved in this paper because of our limited research scope.

Due to the use of Taguchi method, the results obtained are only relative and do not exactly indicate what parameter has the highest effect on the performance characteristic value. Also, this method should not be used with all relationships between all variables are required because orthogonal arrays do not test all variable combinations. In this paper, since after the design variables are specified, use of experimental design may be less cost effective, Taguchi method was applied at early stages of process development. These issues can be solved by using other intelligent approaches such as neural networks. The proposed model results are sensitive to the selection of inputs and outputs because the number of efficient suppliers tends to increase with the number of inputs and output variables. Since a standard formulation of DEA creates a separate linear program for each DMU, considering the non-linear relations between variables of the large problems can be computationally intensive.

6.2 Future research recommendations

For the future researches, we recommend the following directions. Applying hybrid methods (such as genetic algorithms, Bayesian networks and regression models) more than individual ones because they can integrate the benefits of two or more models to solve the supplier selection problem. Developing mathematical and simulation models for determining the optimum order quantity that should buy from the selected suppliers and shows that it is critical to know how much to buy to achieve minimum cost. Also, taking into account inventory problem and integrates it with supplier selection and some of them integrates supplier selection with production planning problem. Therefore, it is supposed to see more integrated papers in the future.

Artificial neural networks (ANNs) are non-linear model that is easy to use and understand compared to statistical methods. Therefore, considering this type of information processing method, in the future studies, leads to use the adaptive learning ability to learn how to do tasks based on the data given for training or initial experience. ANNs have been applied to an increasing number of real-world problems of considerable complexity. ANNs, with their remarkable ability to derive meaning from complicated or imprecise data, can be used to extract patterns and detect trends in supplier selection problem that are too complex to be noticed by either humans or other computer techniques.

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(The Appendix follows overleaf.)

Appendix. The obtained diagrams for the second metrical method are presented below

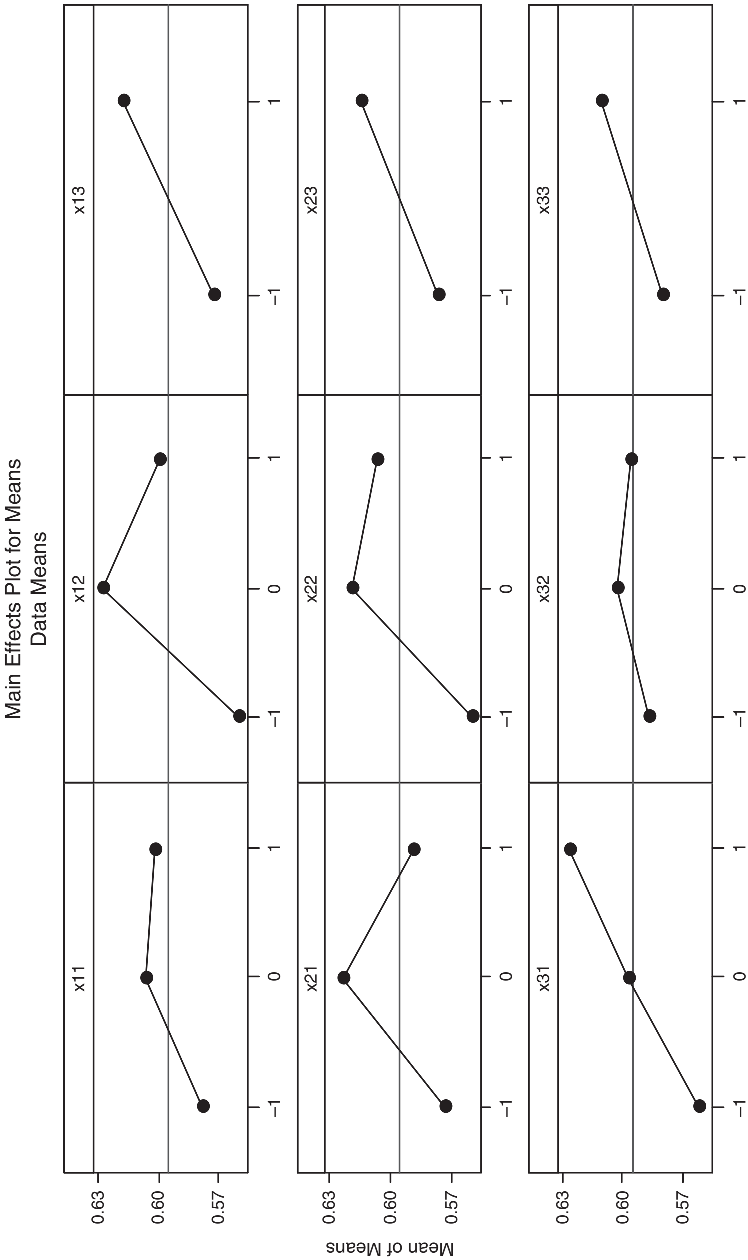

Figure A1.
Diagram of effects of variables on the amount of the second metrical integrative function

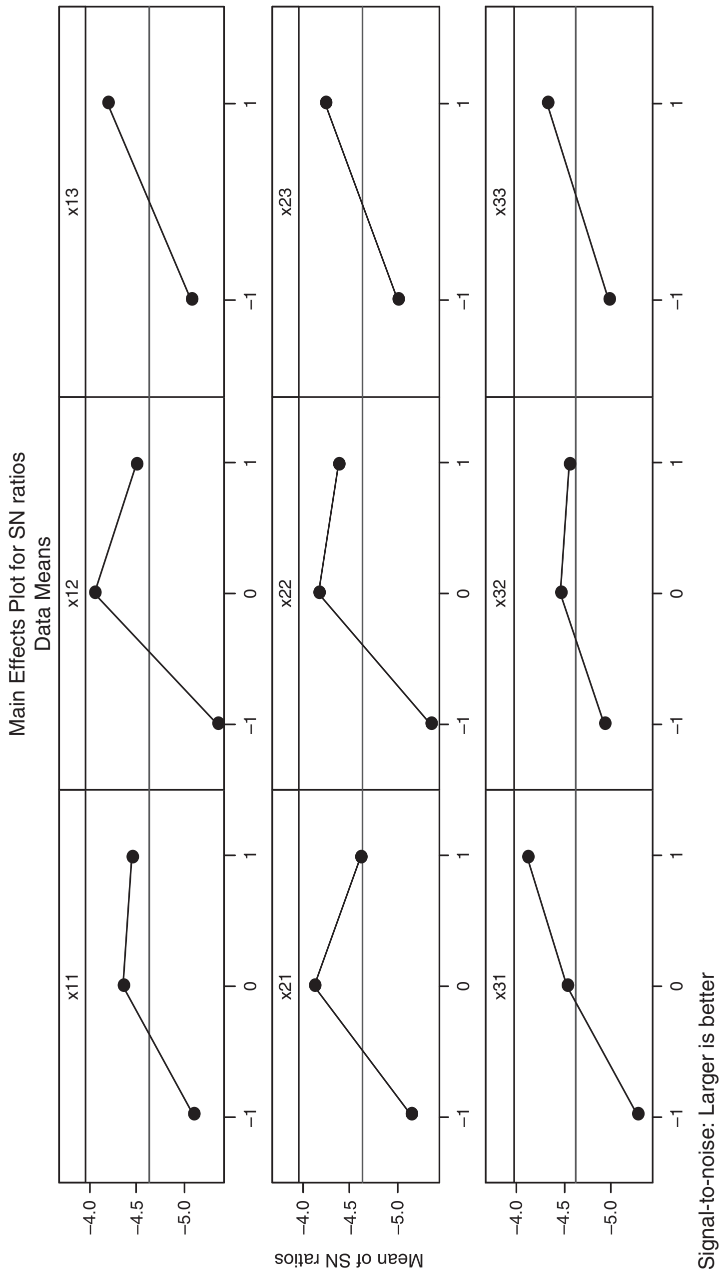

Figure A2.
Diagram of effects of variables on the signal rate to disturbance for the second metrical function

Table AI. Obtained results from Taguchi method

No.	x11	x12	x13	x21	x22	x23	x31	x32	x33	High-quality Products	Benefit	First metrical method	Second metrical method	Function multiplication method
1	0	400	800	300	300	600	0	250	500	0.185	0.937	0.7119	0.6515	0.1740
2	400	400	800	300	300	600	0	250	500	0.643	0.508	0.5487	0.5755	0.3268
3	400	400	800	300	300	600	500	250	500	0.581	0.561	0.5673	0.5713	0.3263

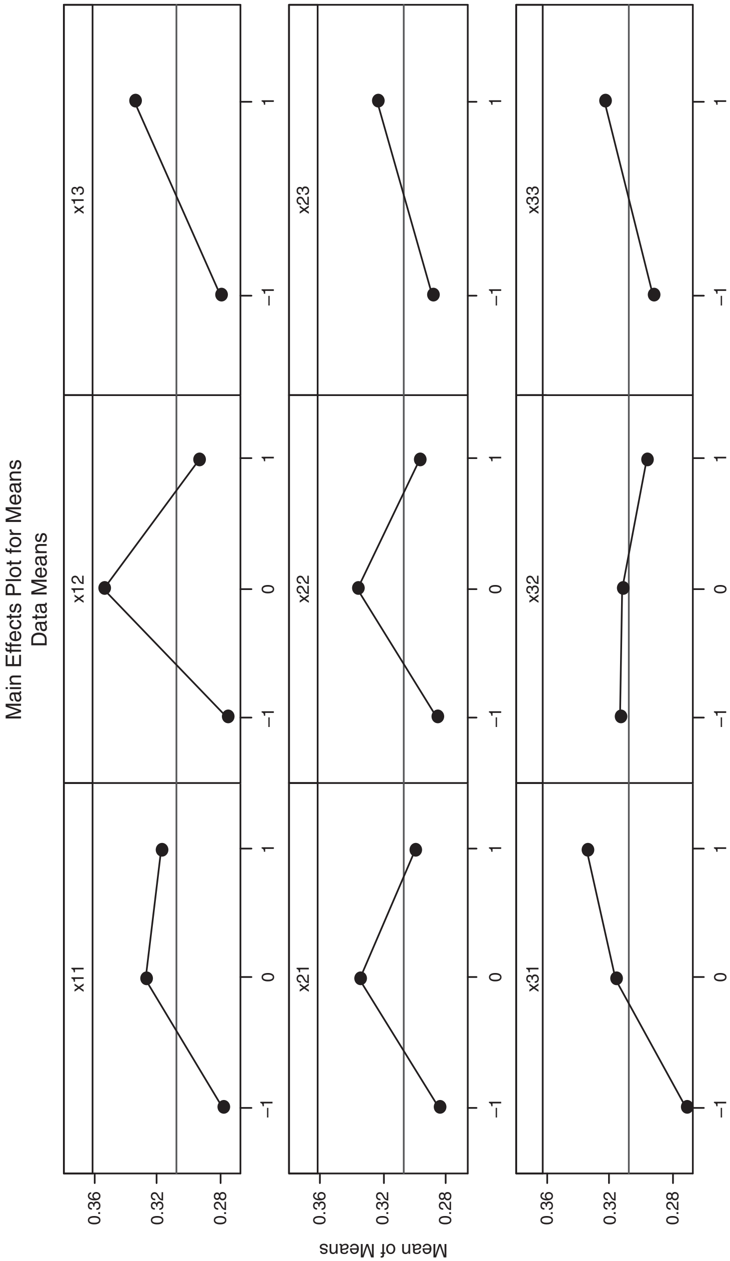

Figure A3.
Diagram of effects of variables on the amount of the multiplied integrative function

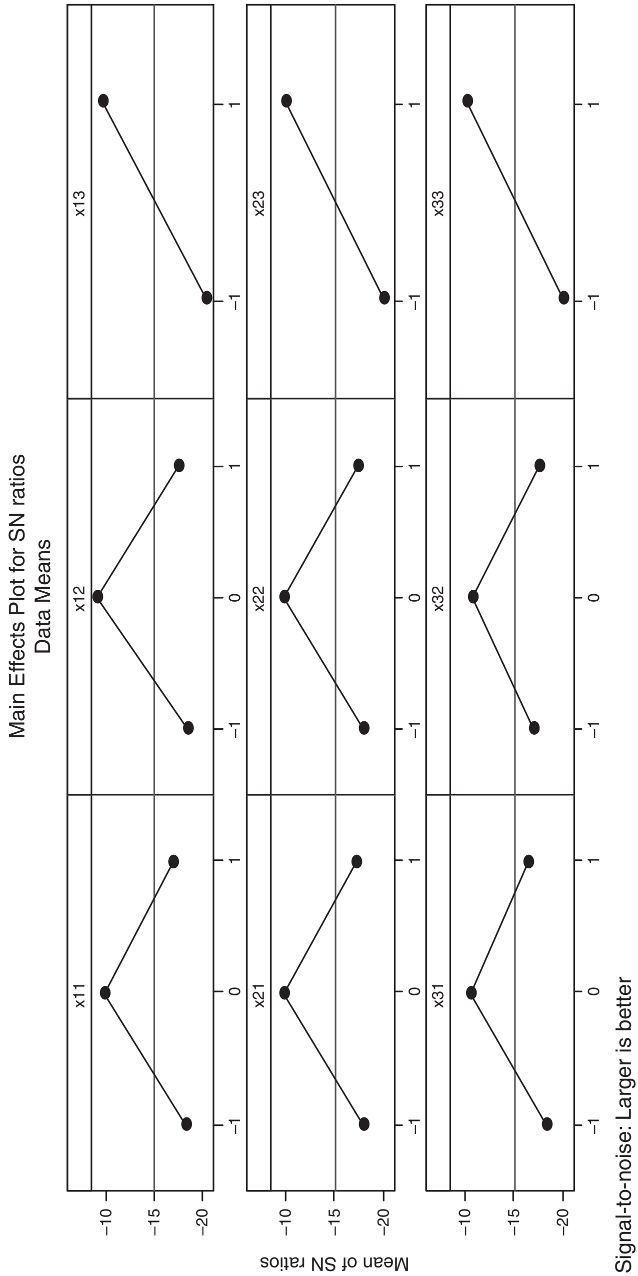

Figure A4.
Diagram of effects of variables on the signal rate to disturbance for the multiplied function

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