**A Green Supplier Selection** **Framework in Polyethylene Industry**

**Abstract**

​To outsource part of their work, organizations are looking for suppliers who also have green criteria with other criteria. Selecting suppliers begins with the definition of potential suppliers and then selects the best among them. In this work, a two-part approach for selecting suppliers consisting of suppliers’ prioritization is presented. In the first part, the criteria that influence on selecting the suppliers have been identified and extracted using the literature review and experts’ opinion which consists of 19 criteria. Then, these criteria were evaluated by the CVR index and using experts' opinions, and finally 16 criteria were selected for selecting green suppliers in a polyethylene’s products producer company in Iran. In the next step, suppliers are selected in a green supply chain using multi-criteria decision making methods such as Dempster-Shafer theory and gray relationship analysis, which is a strategic decision. This study attempts to improve the level of reliance on the whole uncertain degree by combining Dempster-Shafer theory and grey relational analysis, which makes the grey analysis method more robust and its results more reliable.

Keywords: Selecting Supplier, Green Criteria, Grey Theory, Dempster-Shafer Theory

1. **Introduction**

The field of supply chain management and the process of supplier selection is taken into consideration in the literature for the last two decades. Many factories and industry owners have been looking for ways to participate with suppliers to enhance their management and competitiveness on the global stage. The supply chain of the company poses a serious barrier to competitors through the continuity and sustainability of the relationship between suppliers and industry owners (Jafarnejad et al., 2009). Also, on the one hand, creating a long-lasting and sustainable relationship with the supplier will reduce the costs of the supplier. Reducing the supplier costs will cause reducing the costs of the organization (the client). On the other hand, a sustainable relationship enables the supplier to comply with the employer's guidelines, rules and standards and make use of the facilities available to the suppliers such as technical engineering facilities.

Companies and organizations outsource some of the organization's activities. That is, they outsourced them (suppliers). Hence, selecting one or a set of suppliers to outsource the organization's work is critical to the success of the organization. The concept of outsourcing is discussed below. The environmental issues also add to the importance of this problem. Today, many industry owners are seeking to implement a green supply chain in their production and distribution process to satisfy their shareholders and respect their customers' rights. One of these important activities is connecting with green suppliers.

Novelty of this work:

The present study aimed to propose a two-step approach for evaluating and selecting suppliers and optimally allocating them to the green supply chain. The contribution of this work can be categorized as follows:

1. Combining and categorizing criteria and sub-criteria for green supplier selection problem in Polyethylene Industry
2. Another feature of Dempster-Shafer rule is that it highlights the transforming portions of evidence and downplays the conflicting ones (Frittella, 2020). Hence, the Dempster-Shafer Theory is used for this work for evaluating green supplier selection problem.

The Grey System decision-making method is used to evaluate and rank green suppliers and implement the green supply chain management (GSCM) in the production of polyethylene tanks. In this context, proposing a two-step approach for evaluating and selecting suppliers and optimally allocating them is the second novelty of this work.

Thus, the main question of the research is how to design and implement an integrated approach to supplier selection taking into account environmental criteria?

The outline of the work includes the literature review shown in section 2. The Methodology of research is presented in section 3. Section 4 highlights the results and discussion, while section 5 offers the conclusion.

1. **Literature Review**

The tendency for environmentally friendly choices in supply chain management has recently increased dramatically. Formerly, environmental management was a branch of product development, process design, operations, logistics, marketing, regulatory compliance and waste management. However, nowadays it has become clear that environmental management must be an integral part of every operation in progress (Srivastava, 2007).

*2.1 Green Supply Chain Management*

Green design has been widely used in the fields and covers a wide range of disciplines including environmental risk management, product safety, occupational health and safety, pollution prevention, resource conservation and waste management (Fiksel and Fiksel, 1996; Amemba et al., 2013). Green operations relate to all aspects of production and reprocessing, utilization, transportation, logistics, and waste management after final design (Srivastava, 2007).

The goal of green production is to reduce the environmental burden using appropriate materials and technologies (Vrchota et al., 2020), while refurbishment refers to an industrial process in which worn-out products are restored and return to their original state (Lund, 1984). Green design researches have addressed both Environmental Conscious Design (ECD) and the Product Life Cycle Assessment (LCA). Its goal is to gain an understanding of how design decisions affect product compatibility with the environment. A common approach is to use less hazardous materials or processes instead of potentially hazardous materials or processes. This seemingly logical practice is sometimes undesirable if it leads to a rapid depletion of potentially scarce resources or an increase in the production of other environmentally incompatible materials (Graedel, 2002). LCA is a process for assessing and evaluating the environmental, occupational health and resource implications of a product throughout its life cycle, namely the extraction and processing of raw materials, production, transportation and distribution, utilization, reconstruction, recycling, and final disposal (Gungor and Gupta, 1999; Campion, 2015).

Green supply chain management (GSCM) is defined as integrating environmental thinking into supply chain management including product design, sourcing and material selection, production processes, finished product delivery to consumers as well as end-of-life management of the product after its useful life (Srivastava, 2007). GSCM has gained much interest among researchers in supply chain management (Lis et al., 2020). The reason for this growing importance and interest in GSCM can be explained with increasing deterioration of the environment such as reduction of primary resources, overflow of waste disposal areas and increased pollution levels (Srivastava, 2007). However, the importance of green supply chain management is not just about being environmentally friendly, it is also due to a good business sense and greater profits (Wilkerson, 2005). Indeed, this is a parameter to increase business value, not a cost. In addition, legal requirements and customer pressure also drive GSCM. Thus, GSCM ranges from reactive monitoring of environmental management programs to more active practices such as different Rs such as reduction, reuse, rework, refurbishment, repair, recycle, rebuild, reverse logistics, etc (Shaharudin et al., 2019; Yadav and Yadav, 2019).

*2.2 Background of research*

Previously, many studies have been conducted in this area. (Dekker et al., 2012) concluded that important GSCM practices include considering the influence of environmental factors on supplier selection, maintenance, and development. (Lin, 2012) developed an integrated fuzzy network process analysis model combined with a multi-objective linear programming model. In their proposed mathematical model four objective functions are presented three of which are of minimization type including cost minimization, delivery delay minimization, and defective product purchase minimization and one of maximization type namely maximizing total purchase value. (Seuring,2013) reviewed and categorized the literature on sustainable supply chain management including green issues and provided an overview of the status of the subject literature. (Kannan et al., 2013) proposed a hybrid approach based on the Fuzzy Analytic Hierarchy Process (FANP), fuzzy TOPSIS and a Fuzzy Multi-Objective Linear Programming Model for supplier selection in the green supply chain. (Kazemi et al., 2014) presented a multi-objective model for selecting suppliers and allocating orders to them with a discount value. Like other two-step papers reviewed (Arabzad et al., 2014) proposed a hybrid approach based on multi-criteria and multi-objective decision making to select suppliers and optimize their order allocation; however, a managing strategy based on strengths, weaknesses, opportunity, and threat have also been considered in their approach. (Ware et al., 2014a) developed a nonlinear mixed-integer model for dynamic supplier selection. They believe that the problem of selecting suppliers for a dynamic problem should not be used as a one-time evaluation of the results for subsequent periods, but should be done on a regular basis for each evaluation period. In another study by Cui (2014), the problem of supplier selection was considered with regard to production planning. In this model, the flexibility of the customer is considered and their problem is multi-product. Because the proposed model is NP-hard, they have developed a genetic algorithm to find near-optimal solutions. In another work performed by (Ware et al., 2014), a two-step approach consisting of a hierarchical analysis process and a nonlinear mixed-integer programming model is presented like other two-step hybrid studies. In a study aimed at using DEMATEL decision-making techniques in identifying the impacts of carbon management on the green supply chain to improve the overall performance of suppliers in terms of carbon management. (Hsu et al., 2013) identified 13 carbon management criteria in three dimensions using a literature review and interviewing three experts in an electronics manufacturer. (Govindan et al., 2014) focused on identifying barriers to GSCM based on the procurement effect. Based on a comparative analysis of the relevant literature, Robinson (2014) proposed an evolutionary framework for environmental sustainability in ESCM supply chain management. This research aims to provide a framework for research and dialogue between industry executives and academics to examine environmental sustainability in supply chain management for long-term success. (Kumar et al., 2014), examined the supplier selection process which includes a set of activities such as identifying, analyzing, and selecting suppliers to a layer of the supply chain. Haeri and Rezaei (2019) studied a grey-based green supplier selection model for uncertain environments.

According to the literature, many studies have been done on the selection of suppliers. Some of these studies have considered only the selection of a dedicated supplier (strategic approach) and others have also considered order allocation (strategic and operational approach). Due to the antiquity of this issue, there are a few studies conducted in this field in the green supply chain. It should be noted that the studied approaches gain weight from the first stage which is used in the second stage in the mathematical model. In this work, in addition to this issue, in the first stage, using a set of critical criteria the pre-qualification of suppliers will be examined so that eligible suppliers can enter the second stage. In addition, in the reviewed articles, a few of them considered being multi-pro duct and none of them considered routing in this issue. In this study, the assumptions of being multi-product, vehicle routing and green routing will be considered alongside other common assumptions that have not been considered simultaneously in any study so far. The proposed mathematical model is multi-objective and a fuzzy approach will be used to solve it. Based on the reviewed literature, there has not been conducted any work for green supplier selection in the polyethylene industry.

Suppliers that adopt GSCM practices can enhance the company's environmental performance throughout the supply chain. On the other hand, the criteria for evaluating environmental problems are always uncertain. The reason for this is the quality of these criteria. Therefore, this study seeks to provide a method for selecting suppliers based on environmental considerations and under uncertainty. The uncertainties considered in this study will be used to deal with the uncertainties of grey theory and the Dempster-Shafer method will be used to select suppliers.

The present study aim to determine the practical and environmental criteria in selecting suppliers, selecting the most appropriate MCDM method for evaluating suppliers, providing an integrated approach to supplier selection considering the environmental criteria, etc.

In this work, we have reviewed different articles, books, reports, and related criteria to extract the criteria for green supplier selection. Accordingly, some determinants were extracted from the research works as presented in Table 1.

**Table 1** Reviewing Green supplier selection determinants

|  |  |  |
| --- | --- | --- |
| Authors | Year | Determinants |
| Green | Quality | Risk | On-time Delivery | Price | Environmental | Credit | Technology | After Sales Services | Collaboration and flexibility to respond demand |
| Lin | 2009 |  |  |  | 🗹 | 🗹 |  | 🗹 | 🗹 |  |  |
| Bagheri and Tarokh | 2010 |  | 🗹 |  |  | 🗹 |  |  |  | 🗹 |  |
| Kannan et al. | 2013 |  | 🗹 |  | 🗹 | 🗹 | 🗹 |  | 🗹 |  |  |
| Nazari-Shirkouhi et al. | 2013 |  | 🗹 |  | 🗹 |  |  |  | 🗹 |  | 🗹 |
| Sharma and Balan | 2013 |  | 🗹 |  | 🗹 | 🗹 |  |  |  | 🗹 |  |
| Hsu et al. | 2013 | 🗹 |  | 🗹 |  | 🗹 | 🗹 |  |  |  |  |
| Arabzad et al. | 2014 |  |  |  | 🗹 | 🗹 | 🗹 | 🗹 |  | 🗹 |  |
| Ware et al. | 2014 |  |  |  | 🗹 | 🗹 |  |  |  |  |  |
| Cui | 2014 |  | 🗹 |  | 🗹 | 🗹 |  |  |  |  |  |
| Kazemi et al. | 2014 |  | 🗹 |  | 🗹 |  |  |  | 🗹 |  |  |
| Govindan et al. | 2014 | 🗹 | 🗹 | 🗹 | 🗹 | 🗹 | 🗹 |  |  | 🗹 | 🗹 |
| Gurel et al. | 2015 | 🗹 | 🗹 |  | 🗹 | 🗹 | 🗹 |  |  | 🗹 | 🗹 |
| Mousakhani et al. | 2017 | 🗹 | 🗹 |  | 🗹 | 🗹 | 🗹 |  | 🗹 |  |  |
| Lo et al. | 2018 |  |  | 🗹 |  |  | 🗹 |  |  |  | 🗹 |
| Seyed Haeri and Rezaei | 2019 |  | 🗹 | 🗹 | 🗹 | 🗹 |  |  | 🗹 |  | 🗹 |
| Mohammadi and Avakh Darestani | 2019 |  | 🗹 | 🗹 |  | 🗹 | 🗹 |  |  | 🗹 |  |
| Gao et al. | 2020 |  | 🗹 |  |  | 🗹 | 🗹 |  | 🗹 |  |  |
| Oroojeni Mohammad Javad et al. | 2020 | 🗹 |  | 🗹 |  | 🗹 | 🗹 |  | 🗹 |  | 🗹 |
| Sarabi and Avakh Darestani | 2021 |  | 🗹 |  | 🗹 | 🗹 | 🗹 | 🗹 | 🗹 |  | 🗹 |
| Current research | 2021 | 🗹 | 🗹 | 🗹 | 🗹 | 🗹 |  |  |  | 🗹 |  |

1. **Methodology**

Multiple-criteria decision-making (MCDM) methods are used to determine the weights of the evaluation factors. MCDM methods are divided into two categories: multi-attribute decision-making and multi-objective decision making. If the process is done correctly, higher quality and a long-term relationship will be achieved. The Dempster-Shafer intuitive theory is one of the methods in the decision-making process in uncertainty. This theory is important when discussing existing beliefs about a situation or a system of situations. Beliefs about events are not the same but this theory can be used to combine existing evidence in a similar fashion. In this method, among the limited number of options to choose the value of each option, the superior degrees are assigned to each one and ranked accordingly. For this case, selecting alternatives are the same criteria which are on two levels, each of which must be weighed at each level. In the Dempster-Shafer analysis method, the experts determine their selection which are sets of alternatives.

Since the present study aimed to select a green supplier in GSCM of the company using the grey relationship and Dempster-Shafer method, therefore, it will be developmental research that can also be considered as an exploratory study. The executive strategy of this study is a sequential exploration strategy based on its hybrid approach according to Figure 1:

**Figure 1** Framework of Study

*Step Two*: Conducting brainstorming sessions

Simultaneously, with the study of the literature on the subject and extracting the variables affecting the selection of green suppliers in the company, some sessions were held with a groups of experts of the statistical population. They expressed their views on important and effective variables in the selection of green suppliers.

*Step Three*: Selecting and validating the green supplier selection criteria & validation of content

The test validity is the most important factor to consider in evaluating the test. The content validity ratio was used in this study. This model included important criteria and sub-criteria belong to green supplier selection in polyethylene industry. CVR validation refers to a process that aims to provide assurance the questionnaire measures the content area that is expected. One way of achieving content validity is to engage a panel of experts considering the importance of individual items within an instrument (Ayre and John Scally, 2014). CVR has been employed in diverse areas of research and is considered one of the most accepted tools for content validity assessments (Kennedy, 2019).

For validation of the content and criteria considered for this study, Content Validity Ratio Index (CVR) is recommended. For validation, the expert views on the content of the test in question are used to calculate this index and by explaining the objectives of the test to them and providing operational definitions of the content of the question The CVR calculation process is about to done. The experts will be asked to answer each question based on the Likert three-part scale of "necessary", "useful but not necessary" and " It is not necessary” to classify them. Then, the content validity ratio is calculated according to the following formula (Lawshe, 1975):

|  |  |
| --- | --- |
| (1) | CVR =$\frac{n\_{E-}N/2}{N/2}$  |

In which nE is the number of experts who selected the "necessary" option and N is the number of all the experts.

Based on the number of experts evaluating the questions, the minimum CVR acceptable should be based on Table 2. Questions for which the calculated CVR value is lower than the target value given the number of evaluating experts should be excluded from the test because they do not have acceptable content validity based on the content validity index.

**Table 2** Minimum acceptable CVR based on the number of scoring experts

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Number of experts | CVR | Number of experts | CVR | Number of experts | CVR |
| 5 | 0.99 | 11 | 0.59 | 25 | 0.37 |
| 6 | 0.99 | 12 | 0.56 | 30 | 0.33 |
| 7 | 0.99 | 13 | 0.54 | 35 | 0.31 |
| 8 | 0.75 | 14 | 0.51 | 40 | 0.29 |
| 9 | 0.78 | 15 | 0.49 |  |  |
| 10 | 0.62 | 20 | 0.42 |  |  |

The information obtained in the previous three steps on identifying the most important variables for selecting green suppliers in the company was summarized at this stage. Finally, 16 criteria in 6 categories were used to make a questionnaire for selecting green suppliers.

*Step Four*: Collecting quantitative data

A questionnaire was used for data collection. In order to collect and analyze the data, we need to determine the number of required experts (sample size). After determining the sample size, questionnaires were distributed and collected. 16 important criteria obtained from the analysis of the qualitative part of the research were used in the questionnaire. Statistical methods were used to analyze the results of the questionnaire using SPSS software.

Finally, the obtained results have led to the identification of key and effective indicators in the decision-making process for selecting green suppliers in the company.

*Step five:* Determining the degree of uncertainty (Grey Relational Analysis)

The basic idea of the grey theory is to attempt to visualize the overall system by focusing on partial or finite information about a system. Therefore, this methodology deals with uncertain, incomplete, and weak problems. One of the major advantages of grey system theory is that it can produce satisfactory outputs using relatively small amounts of information with high variability in criteria. Each grey system is described by grey numbers, grey equations, and grey matrices. The grey number can be defined as a number with uncertain information. In this research, the criterion rank in this problem is expressed as linguistic variables with a numerical range of one to nine. These numbers will contain uncertain information.

Grey Relational Analysis (GRA) is used to solve uncertain problems with discrete data and incomplete information. This theory generates satisfactory outputs using relatively little information and with great variability in criteria. Like the fuzzy theory Grey theory is an effective mathematical model for solving ambiguous problems (Deng, 1982). This theory has been applied in many areas such as solving MCDM problems called grey relational analysis. Grey relationship analysis is a part of the grey theory which is used to solve problems that have complex relationships between factors and their variables (Moran et al., 2006). Grey systems theory is an algorithm that analyzes the uncertain relationships of members of a system with a reference member. The details of the grey relational analysis process are as follows:

Grey Relational Generating: The effect of some indices may be ignored when the performance measurement units of different indices are different. This may also happen when some performance indicators are wide-ranging. Also, if the purpose or direction of these indicators is different, incorrect results are obtained in the analysis. Therefore, it is necessary to convert all the functional values ​​of each option into a comparative series in a process similar to normalization. This process is called the grey relational generation in grey systems theory.

In a MCDM problem that has the m alternatives and the n index, the ith alternative can be expressed as $y\_{i}=\left(y\_{i1},y\_{i2},…,y\_{ij},…,y\_{in}\right)$, so that $y\_{ij} $is the function value of j index for the alternative i. The expression Yi can be transformed into a series of comparisons $X\_{i}=\left(x\_{i1},x\_{i2},…,x\_{ij},…,x\_{in}\right)$ by one of the relations (2), (3), or (4).

|  |  |
| --- | --- |
| (2) | $$x\_{ij}=\frac{y\_{\begin{array}{c}ij\\ \end{array}}-Min\left\{y\_{\begin{array}{c}ij\\ \end{array}}, i=1,2,…,m\right\}}{Max\left\{y\_{\begin{array}{c}ij\\ \end{array}}, i=1,2,…,m\right\}-Min\left\{y\_{\begin{array}{c}ij\\ \end{array}}, i=1,2,…,m\right\}} ∀i=1,2,…,m , j=1,2,…,n$$ |
| (3) | $$x\_{ij}=\frac{Min\left\{y\_{\begin{array}{c}ij\\ \end{array}}, i=1,2,…,m\right\}-y\_{\begin{array}{c}ij\\ \end{array}}}{Max\left\{y\_{\begin{array}{c}ij\\ \end{array}}, i=1,2,…,m\right\}-Min\left\{y\_{\begin{array}{c}ij\\ \end{array}}, i=1,2,…,m\right\}} ∀i =1,2,…,m , j=1,2,…,n$$ |
|  (4) | $$x\_{ij}=\frac{\left|y\_{\begin{array}{c}ij\\ \end{array}}-y\_{j}^{\*}\right|}{Max\left\{Max\left\{y\_{\begin{array}{c}ij\\ \end{array}}, i=1,2,…,m\right\}-y\_{ij}^{\*},y\_{ij}^{\*}-Min\left\{y\_{\begin{array}{c}ij\\ \end{array}}, i=1,2,…,m\right\}\right\}} $$$$∀i=1,2,…,m , j=1,2,…,n$$ |

Relation (2) is used for the "the larger, the better" index, (3) is used for the "the smaller, the better" index and (4) is used for “the closer to the desired value $y\_{j}^{\*}$, the better”.

Reference Sequence Definition: after creating grey relational using Equations 2 to 4, all functional values ​​are scaled [0 and 1]. If for an index j in alternative i, the value of $ x\_{ij } $generated by the greying process equals 1 or is closer to 1 than the value of any other alternative, it means that the function of alternative i in index j is better than other alternatives. Therefore, if there is one alternative for all performance values, this would be the best choice. This research defines the target reference series as $X\_{0}=\left(x\_{01},x\_{02},…,x\_{0j},…,x\_{0n}\right)=\left(1,1,…1,…,1\right)$ and then searches for an alternative that its comparative series are closer to this target series.

Grey Relational Coefficient Calculation: The Grey Relational Coefficient Calculation is used to determine the approximation of $ x\_{ij }$to $x\_{0j}$. The greater the grey correlation coefficient, $ x\_{ij }$is closer to $x\_{0j}$. The grey relational coefficient can be calculated using Equation 5:

|  |  |
| --- | --- |
| (5) | $γ\left(x\_{0j},x\_{ij}\right)=\frac{∆Min+ζ∆Max}{∆\_{ij}+ζ∆Max} i=1,2,…m j=1,2,…,n$  |

In Equation 5, $γ\left(x\_{0j},x\_{ij}\right) $represents the grey correlation coefficient between $ x\_{ij }$and $x\_{0j} $where:

$$∆\_{ij}=x\_{0j}-x\_{ij}$$

$$∆Min=Min\left\{∆\_{ij},i=1,2,…,m;j=1,2,…,n\right\}$$

$$∆Max=Max\left\{∆\_{ij},i=1,2,…,m;j=1,2,…,n\right\}$$

$ζ ϵ\left[0,1\right]= $coefficient of detection

The purpose of applying the coefficient of detection is to extend or narrow the range of the grey correlation coefficient.

Grey Relational Grade Calculation: after calculating all the grey relativity coefficients $γ\left(x\_{0j},x\_{ij}\right)$ the grey relational grade can be calculated using Equation 6:

|  |  |
| --- | --- |
| (6) | $$Γ\left(x\_{0},x\_{i}\right)=\sum\_{j=1}^{n}w\_{jγ}\left(x\_{0j},x\_{ij}\right) i=1,2,…,m$$ |

Equation 6 shows the rank of the grey relation between $x\_{i} $and $x\_{0}$. Indeed, this expression indicates the correlation between the objective reference series and the comparative series. $w\_{j} $is the weight of the index j, which usually depends on the decision maker or the proposed problem structure. In addition, $\sum\_{j=1}^{n}wj=1$ as mentioned earlier, on each indicator the objective reference series represents the best performance among the comparable series. Therefore, if a comparative series for an option has the highest grey relational grade with the objective reference series, it means that the comparative series has the most similarity to the objective reference series, and so this alternative is the best choice.

Step Six: Dempster-Shafer Method

In uncertainty situations, data integration is very important that Bayesian theory, fuzzy logic, and evidence theory are known as effective methods. There is no general consensus on the global application of methods, but Dempster-Shafer theory is one of the popular theories applied in intelligent systems for modeling and reasoning when uncertainty and precision inaccuracy are involved. In Dempster-Shafer theory the Dempster's rule of combination is a powerful tool that is important for combining evidence from distinct information sources and is a potential tool for assessing risk and reliability in engineering applications where measurement is impossible. Experiments and the acquisition of knowledge from the inference of experts are used. One of the important aspects of this theory is the combination of evidence from different sources and the modeling of conflict between them (Santz and Ferson, 2002). Finally, the combination of the grey relational and the Dempster-Shafer theory of evidence is used.

The target population of the research is the experts of the company, whose sample members have been selected by purposive sampling method. Due to the limitations imposed and using Equation 7 for determining sample size in a limited population and for random sampling 10 people were selected as a statistical sample.

|  |  |
| --- | --- |
| (7) | $\hat{n}\_{0}=\frac{^{pq}/\_{υ}}{1+^{1}/\_{N}(^{pq}/\_{υ}-1)} $  |

The following are the criteria used by the experts for the supplier selection:

Green criterion: The Company must consider the full description of the environment, human health and product safety in the process of acquiring, producing, distributing raw materials and aiming to prevent contamination at the source. The company should also consider choosing an environmentally friendly product and service to use and deal with any waste product that may be harmful to the environment.

Quality criterion: It is the amount of compliance with the requirements that must be specified in order to measure the cost of non-compliance. Accordingly, a set of characteristics associated with the product or service used includes marketing, engineering, production, and maintenance through which the product or service can meet customer expectations (Crosby, 1979; Deming, 1982).

Risk criteria: The risk of suppliers in the supply chain is defined as anything that disrupts or impedes the information, product flow or material of the original supplier.

On-time Delivery criteria: The timely delivery of the product or service is one of the key items that directly affect the creation and improvement of customer satisfaction or dissatisfaction with the products of a manufacturing or service company. On-time delivery is one of the key factors in the success of an organization's business. Timeliness is more important in the B2B business (Dickson, 1966).

Price: The price is the value of an object expressed in money (Aeni et al.,2019). Price is the propensity of consumers to measure the appropriateness of the benefits of products and services. The meaning of the price of the profit of a good or service depends on the understanding of the consumer which is motivated by the environment and the condition of the individual (Kotler and Armstrong, 2012).

After Sales Services:After-sales services play a major role in the purchasing decisions of consumers (Kurata and Nam, 2010). A crucial competitive strategy in the durable consumer product industry is after-sales services. They allow more revenue and profit to be captured by a producer and a retailer.

([Kurata](https://www.sciencedirect.com/science/article/abs/pii/S0925527313000819%22%20%5Cl%20%22%21) and [Nam](https://www.sciencedirect.com/science/article/abs/pii/S0925527313000819#!), 2013).

Both qualitative and quantitative data were collected for the purpose of this study. Hence, both qualitative tools such as brainstorming and content analysis of subject literature have been used as well as quantitative tools such as questionnaires. In addition to the high content validity obtained through the participation of experts in identifying key variables for the selection of green providers, the questionnaire was again provided by a number of experts and the owners to improve the content and face validity. The comments were submitted to the company and were put into effect after their corrective comments were made.

Reliability coefficient:

Using data from the pilot study, the calculated reliability coefficient for the questionnaire was 0.95. This indicates the internal consistency and high reliability of the questionnaire.

Descriptive statistics were used to analyze the questionnaire data. At the level of descriptive statistics, it is used to describe the data. In descriptive statistics the information obtained from a group describes the same group and the information obtained is not generalized to similar categories. Descriptive statistics were used to describe the data by SPSS software.

Then, the combination of grey relationship analysis and Dempster-Shafer method was used by entering the input data into it and analyzing the data by this combination of effective factors for the design and implementation of the system and for the final output. We use MATLAB software to calculate the combined method.

Step 1: Calculating the average degree of grey relationship between $x\_{ij} $and $∆x\_{ij} $as follows:

$r\_{ij}=\frac{\min\_{1\leq i\leq m}∆x\_{ij}+0.5\*\max\_{1\leq i\leq m}∆x\_{ij}}{∆x\_{ij}+0.5\*\max\_{1\leq i\leq m}∆x\_{ij}} (i=1,2,…,m,j=1,2,…,n).$ (8)

Step 2: Calculating the degree of uncertainty of each criterion as follows:

$DOI\_{j}=\frac{1}{n}(\sum\_{i=1}^{m}(r\_{ij})^{2})^{\frac{1}{2}} (j=1,2,…,n).$ (9)

Step 3: Calculating the structure of the image sequence information for each $x\_{j}$ based on the criteria and forming its matrix as follows:

$\tilde{x\_{ij}}=\frac{x\_{ij}}{\sum\_{i=1}^{m}x\_{ij}} (i=1,2,…,m, j=1,2,…,n).$ (10)

Step 4: Calculating the density function value for each option and for each alternative compared to each criterion as follows:

$m\_{ij}(Or m\_{j}(i))=\tilde{x\_{ij}}(1-DOI\_{j}) (i=1,2,…,m, j=1,2,…,n$ (11)

$m\_{Θj}(Or m\_{j}(m+1))=1- \sum\_{i=1}^{m}m\_{ij} ( j=1,2,…,n)$ (12)

Step 5: Calculating the size of each alternative trust as follows:

$Bel(A)=m\_{1}⨂m\_{2}…⨂m\_{n}(A)=\frac{1}{1-K}\sum\_{\bigcap\_{i=1}^{n}A\_{i}=A, A\_{i}⊆Θ}^{}m\_{1}(A\_{1})m\_{2}(A\_{2})…m\_{n}(A\_{n})$ (13)

$Where A⊆Θ, A\ne ∅, and K=\sum\_{\bigcap\_{i=1}^{n}A\_{i}=∅, A\_{i}⊆Θ}^{}m\_{1}\left(A\_{1}\right)m\_{2}\left(A\_{2}\right)…m\_{n}\left(A\_{n}\right)<1 $ (14)

1. **Results**

The company was established for manufacturing of different ranges of Polyethylene Products in vast variations about 700 numbers of productions in 1988 in Urmia. Six criteria of risk, timely delivery, quality, cost, after-sales service, and greenness were employed for evaluation. The company produces various types of polyethylene multilayer tanks, industrial components, types of tubs, various recreational Boats, Marine and Fishery supplies, urban furniture as well as all traffic safety signs and elements (Mirzadeh, 2017). Based on the methodology, the final criteria are validated by experts after collecting expert’s opinions according to Table 3. Some of the products of the company are presented in Figure 2.



Figure 2 Company’s products varieties

Final green suppliers as well as the coding assigned to each supplier are provided in Table 3.

**Table 3** Final green supplier selection criteria sub-criteria as well as coding

|  |  |  |
| --- | --- | --- |
| Code | Sub-Criteria | Criteria |
| G1 | Air pollution | Green (G) |
| G2 | Compliance with environmental standards (ISO 14001) |
| G3 | Purchasing environmentally friendly raw materials |
| G4 | Environmental Protection |
| G5 | Green packaging |
| G6 | Recycling (reprocessing of waste into reusable materials) |
| G7 | Access to clean technology for reverse logistics |
| Q1 | Implementation of Quality Management system (ISO9001) | Quality (Q) |
| Q2 | Suppliers satisfaction records |
| Q3 | Quality level of Services |
| R1 | Success in problem solving | Risk (R) |
| R2 | Reputation and performance |
| O1 | Improving Delivery time | On-time Delivery |
| O2 | Rapid prototyping techniques |
| C1 | Price | Price |
| V1 | After sales service | After Sales Services |

The weights obtained from the expert opinion by compiling survey questionnaires as well as the local weights of the criteria are provided in Table 4.

**Table 4** Weights and the local weights of the sub-criteria.

|  |  |  |  |
| --- | --- | --- | --- |
| Expert opinion on the importance of sub-criteria | Local weight of the sub-criteria of each criterion | Green Supplier Selection Sub-Criteria | Code |
| 4.30 | 0.111 | Air pollution | G1 |
| 1.80 | 0.047 | Compliance with environmental standards (ISO 14001) | G2 |
| 2.00 | 0.052 | Purchasing environmentally friendly raw materials | G3 |
| 2.90 | 0.075 | Environmental Protection | G4 |
| 3.00 | 0.078 | Green packaging | G5 |
| 1.10 | 0.028 | Recycling (reprocessing of waste into reusable materials) | G6 |
| 3.00 | 0.078 | Access to clean technology for reverse logistics | G7 |
| 2.00 | 0.052 | Implementation of Quality Management system (ISO9001) | Q1 |
| 1.00 | 0.026 | Suppliers satisfaction records | Q2 |
| 2.00 | 0.052 | Quality level of Services | Q3 |
| 3.30 | 0.085 | Success in problem solving | R1 |
| 3.30 | 0.085 | Reputation and performance | R2 |
| 2.80 | 0.072 | Improving Delivery time | O1 |
| 2.20 | 0.057 | Rapid prototyping techniques | O2 |
| 2.80 | 0.072 | Price | C1 |
| 1.20 | 0.031 | After sales service | V1 |

Figure 3 shows the ranking of green supplier selection sub-criteria for this work. Based on the obtained results air pollution, success in problem solving, reputation and performance are among the most important attributes of green supplier selection (Figure 3).

**Figure 3** Weighting of sub-criteria

According to the results the risk criteria (R1) and the first criterion of greenness (G1) are more important to experts.

The average of each alternative is calculated for all criteria and is presented in Table 5.

**Table 5** Average rating of each supplier.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Supplier No. | Supplier 1 | Supplier 2 | Supplier 3 | Supplier 4 | Supplier 5 | Supplier 6 |
| Average rating of each alternative ($\tilde{x\_{i}}$) | 0.038 | 0.022 | 0.036 | 0.026 | 0.042 | 0.041 |

As can be seen from Table 5, the average supplier ratings for suppliers 5 and 6 is higher than other suppliers.

At this stage, the degree of uncertainty for each criterion is calculated as presented in Table 6. This index is calculated for each criterion as the average degree of grey relationship. The larger the value, the lower the impact of the criterion on the whole of the calculations and shows its next effect as “1- degree of uncertainty”. In this study, the criteria G3, R1, and Q1 are high uncertainty criteria.

**Table 6** Sub-criteria uncertainty degree matrix

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Q2 | Q1 | G7 | G6 | G5 | G4 | G3 | G2 | G1 | Criterion |
| 0.077 | 0.121 | 0.117 | 0.115 | 0.099 | 0.082 | 0.128 | 0.073 | 0.102 | $$DOI\_{j}$$ |
|  | V1 | C1 | O2 | O1 | R2 | R1 | Q3 | Criterion |
|  | 0.112 | 0.072 | 0.109 | 0.108 | 0.107 | 0.126 | 0.075 | $$DOI$$ |

Next, the evaluation matrix is ​​made up of these 16 criteria and 6 suppliers and is ranked based on Dumpster Shafer's calculus method calculations and grey supplier relationship analysis. The results of this method show that supplier 2 is selected as the first priority and suppliers 1 and 6 are ranked respectively afterward according to Table 7.

**Table 7** Size of each alternative trust

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Supplier No. | Supplier 1 | Supplier 2 | Supplier 3 | Supplier 4 | Supplier 5 | Supplier 6 |
| Size of each alternative trust | 0.0263 | 0.0310 | 0.0019 | 0.0118 | 0.0007 | 0.0151 |
| Ranking | Second | First | Fifth | Forth | Sixth | Third |

The priority order of suppliers is presented in Figure 4.

**Figure 4** Green Suppliers Ranking

As mentioned earlier, the present study was conducted to find an optimal approach to selecting suppliers in the green supply chain.

To validate the method, we benchmark the result of this work with Wu (2009). Four criteria were selected for that work such as product late delivery, cost, risk factor and supplier’s service performance and five suppliers through using three experts for judgement. The ranking of suppliers using grey related analysis and Dempster–Shafer theory. The ranking of suppliers was as follows:

 Supplier 4 > Supplier 1 > Supplier 3 > Supplier 2 > Supplier 6 > Supplier 5

We employed five criteria including green criteria, 10 experts and five suppliers. The result shows the ranking of suppliers are as follows:

Supplier 2 > Supplier 1 > Supplier 6 > Supplier 4 > Supplier 3 > Supplier 5

However, it should be revealed that studies used different case studies for applicability of proposed methods for their work.

1. **Discussion**

MCDM techniques with uncertainty have been used for the purpose of this study. Generally, the approach presented in this study can be divided into two parts. In the first part, using the literature review and experts' opinions, effective criteria in selecting suppliers have been identified and extracted. the experts determined their selection for choosing main criteria and the accuracy of the verification data was used as an indicator for extraction. Using MCDM techniques such as the Dempster-Shafer method and analyzing grey relationships suppliers were selected in a green supply chain that was a strategic decision. In this research, it was tried to combine two methods of Dempster-Schafer and grey relations analysis to improve the confidence in the total uncertainty and to make the grey analysis method and its results more reliable. In this work, six suppliers belonging to a polyethylene producer were evaluated according to 16 criteria. Data analysis and evaluation illustrated that $G\_{1}$ ranked first under different weights and $R\_{1}$ came in second which means risk and green indicators were more important among other indicators and second supplier and first suppliers were ranked as first and second by this evaluation for further cooperation. As a result, the selected factors are important factors that need more attention by the company's employees. We also compared our method with other classification methods. The results showed that the combination of the two methods of Dempster-Schafer and grey theory in this case has a higher classification accuracy. This approach can help reduce the uncertainty arising from people's cognitive awareness, raise the level of decision-making, allow companies to overcome the problem of selecting the appropriate level of uncertainty and to deal with uncertainty in a practical and justified way.

*Discussion:*

To discuss and validate the results of this study with previous studies, Gao et al., 2020 also selected and highlighted green product, environmental management and quality employing a group consensus decision-making framework to choose the best green supplier for electronics manufacturing. Moreover, it is consistent with the research of Seyed Haeri and Rezaei (2019) carried out a combined BWM and fuzzy grey cognitive green supplier selection for motor vehicle manufacturing case studies. They proposed 10 criteria for evaluating five suppliers using five experts’ opinions and it was concluded that technology capability and management commitment are significantly influencing other criteria in their study. To benchmark our work with Seyed Haeri and Rezaei (2019), it can be revealed that quality, price, delivery, technology, green image, were resulted among important measures selected for both studies which validate selected measures for the model.

However, for this work six criteria and 16 sub-criteria were chosen through reviewing literature and experts’ opinions which shows the importance of some other criteria in polyethylene industry than vehicle parts in automotive industry. In addition, Dempster-Shafer Theory was another aspect employed in this work. This theory is a powerful tool for modeling uncertainty which can help to have more accurate information in conditions of uncertainty ; it can also effectively combine multiple pieces of evidences and beliefs (Fei, 2021). In addition, despite the plenty of studies proposing green supplier selection models, there is a limited number of works using Dempster-Shafer Theory for polyethylene industry.

Moreover, we found that green and risk criteria are ranked higher than other criteria. In a deep investigation, air pollution and success in problem solving skills are among those sub-criteria ranked as first and second. In addition, in this study, 10 experts were considered for judgement and Dempster-Shafer theory and grey relational analysis as methodology for supplier evaluation.

To compare the ranking using other MCDM techniques, Oroojeni Mohammad Javad et al. (2020) selected TOPSIS and Best Worst method (BWM). The BWM was employed to rank the various criteria of green supplier selection in the MCDM problem. Then, the Fuzzy TOPSIS was considered to prioritize the different vendors. Based on the obtained result from their study, the environmental and green criteria are among those criteria that need more attention for green supplier selection assessment. Based on the literature, our study also considered risk criteria as one of the most important criteria into computation. ​Based on the results, we ranked both criteria and sub-criteria of the green supplier selection problem. It can be concluded that risk criteria is an important criteria which needs more attention by practitioners in the Polyethylene Industry.

*Research Implication*

Environmental implications:

By considering green thinking and green supply chain in service and production, executives in cooperation with green suppliers effectively impact on environmental hazards and it leads to higher social satisfaction. Given the importance of environmental issues and more customer attention to this issue, as well as the requirements and laws to consider environmental considerations by industries, It is recommended to establish standards for the purchase of raw materials in terms of a technical and environmental point of view. The way to do the least damage to the environment. Also, various organizations and industries should develop the culture of observing environmental issues within themselves and through social tools such as holding conferences and seminars, inform the fans of their organization about environmental issues to the community and the target market. Establishing multilateral cooperation in the field of environmental issues, cooperation of companies with customers for ecological design, is one of the advantages of holding such seminars. Moreover, criteria for reducing energy consumption should be set through continuous analytical review of the working condition of machinery, equipment, and tools. Green principles are observed in the design of products and work processes in such a way that it is accompanied by saving resources and observing environmental standards. Principles such as investment recovery, green purchasing, environmentally friendly design, green management, green production, etc. As green and risk criteria are amongst first and second most important criteria in the ranking, the implication for practitioners is to concentrate more on green initiatives and procedures. Implementing 14001 would be also one of the most important management systems which helps executives to manage the risk and environmental impact simultaneously.

Economic implications:

Based on the results, green supply chain and risk management are amongst the most important indicators in the polyaniline industry. Giving priority to environmental aspects and hazards can lead to reduced costs and create added value for companies and enterprises. By identifying and limiting the use of hazardous substances, products that are free of hazardous substances are presented. This method can be used as a competitive advantage. Since risk management deals entirely with the processes of identifying analysis and responding to any uncertainty, by identifying environmental hazards, risk can be reduced or even eliminated, which in turn increases added value.

Future research also may be directed by considering other criteria such as executive capability, sustainable development criteria etc. in multi-criteria decision making and other objective functions in the mathematical modeling problem in the supply chain using optimization methods and meta heuristic algorithms. Moreover, including the issue of routing vehicles, rail transport or a combination of these in selecting suppliers. Finally, incorporating the applicable constraints on the political and social barriers in purchasing products from suppliers also would be suggested. **References**

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