# SUPPLIER SELECTION FOR A PUMP MANUFACTURING ORGANIZATION BY HYBRID AHP-TOPSIS TECHNIQUE AND ITS IMPACT ON INVENTORY

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**ABSTRACT**

In today's highly competitive market, organized supply chain management strategy is required by any manufacturing organization to ensure success in both a quantitative and qualitative manner. In order to obtain green manufacturing or a Green Supply Chain Management system, the suppliers should play an important role. Green manufacturing has an impact on inventory also. This paper describes the supplier selection model using a hybrid AHP-TOPSIS technique related to a pump manufacturing industry that intends to enhance Green Purchasing of inventory items. Different criteria that have a good impact on inventory and the environment are considered for supplier selection. First, the Analytic Hierarchy Process (AHP) is used to determine the weight of each criterion, and then the TOPSIS algorithm is applied to optimally select the supplier. In this work, the ranking of suppliers has effectively chosen the selection of an appropriate supplier maintaining a green supply chain management (SCM) system.

Keywords: Green manufacturing; supply chain management; green SCM; supplier selection; pump manufacturing industry; green inventory; AHP; TOPSIS; hybrid AHP-TOPSIS

## 1. Introduction

A proper supply chain management system is required to fulfill the demands of a customer and to ensure profitability. Companies in any supply chain should focus on inventory management along with management of production, transportation, etc. To obtain a green supply chain management system, environmentally sustainable inventory is necessary. A green supply chain deals with promotion of green or eco-friendly products in a supply chain. The suppliers who provide eco-friendly products may be termed as green suppliers. The selection of a green supplier may be an objective for purchasing the inventory items if environmental sustainability is of prime concern. Besides environmental issues, product quality, procurement cost, lead time of the procured inventory items, etc. have immense importance in supplier selection. Selection of wrong suppliers may hamper financial and operational conditions of the supply chain as well as the production. There are many different criteria related to available appropriate suppliers, and it often becomes difficult to select the best supplier to satisfy all the criteria optimally. The supplier selection can be done easily by different multi-criteria decision making (MCDM) techniques. The MCDM techniques provide a way to choose the green supplier methodically.

This paper aims at selection of a green supplier for a pump manufacturing organization. The selection process leads to purchasing of environmentally-friendly inventory items which confirm less waste generation, recyclability, reusability, low energy consumption criteria, etc. In this context, the ranks of the suppliers are determined by their green performance that deal with the utilization of minimum resources, and protection of the environment from pollution.

## 2. Literature Review

Decision making plays an important role in every perspective of a manufacturing organization. Decision making becomes difficult when it deals with multiple criteria. A proper decision making technique is needed to solve problems like this. T.L. Saaty introduced a multi-criteria decision making theory known as the Analytic Hierarchy Process (AHP). A decision hierarchy was constructed in the AHP with a proper goal, criteria and alternatives. A pairwise comparison matrix was formed for different criteria. Comparison between the alternatives, selection of scale, checking of consistency ratio and judgment of alternatives were done using an illustration. Saaty (1977) analyzed the scaling technique for priorities in a hierarchical structure. The consistency of a pairwise comparison matrix was described for different priority levels. The comparison of different scales was discussed and the conversation was extended to the multi criteria decision making technique. Finally, this decision making technique was incorporated for a large scale problem. Saaty (1990) applied AHP method in a hierarchy structure to solve the multi criteria decision making problem. The priorities of different attributes, ranking and other measurements related to AHP were summarized through this research work.

Supplier selection requires a multi-criteria decision making approach to adopt in a quantitative as well as a qualitative manner. Kahraman et al. (2003) used Fuzzy-AHP technique to choose one of the best suppliers based on some criteria of a manufacturing industry. Bayazit et al. (2006) introduced an AHP based extended analysis of a supplier selection problem for a Turkish construction company. Afterwards, a sensitivity analysis was also performed, and the best supplier was selected between two top suppliers. Tahriri et al. (2008) described the AHP based multi-criteria decision making model for selecting the best supplier of a steel manufacturing company in Malaysia using both qualitative and quantitative criteria. The research work introduced the optimal order quantities and lead time among different suppliers by a systematic execution of the AHP model. Lee et al. (2009) used Delphi technique to differentiate the traditional supplier and green supplier. Ultimately, the selection of the best supplier was done in that work by Fuzzy Extended Analytic Hierarchy Process (FEAHP).The sustainability of green production technology was improved by the supplier selection model also. UmaDevi et al. (2012) applied the AHP technique to select the right vendor for a manufacturing industry. Different critical criteria were selected for the vendor selection model, and according to these criteria the best supplier was selected. It was considered to be a great strategic decision by the decision makers. Lei et al. (2013) established the importance of Corporate Social


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Responsibilities (CSR) on supply chain. Seven criteria and different sub-criteria were chosen to select the best supplier under CSR environment. This paper concluded with the preferential judgment of different criteria by AHP technique. Aouadni and Rebai (2013) developed a mixed integer non-linear programming model for an inventory management decision and random supplier selection to solve supply uncertainty problems. The Genetic Algorithm (GA) was also used to solve the problem. Supplier selection may be done by the group of decision makers to avoid criticality of the task. Dragincic and Vranesevic (2014) proposed a group decision making technique for supplier selection which was based on the AHP. The AHP based decision making approach was implemented for supplier selection of irrigation equipment. Further, this approach was adapted in the field of water planning, management and development also. Galankashi et al. (2015) measured the green performance of suppliers by Nominal Grouping Technique (NGT) with respect to the critical criteria of supply chain. Finally, weights of criteria were calculated by Fuzzy Analytical Networking Process (FANP). A hybrid supplier selection model by combining the AHP and Multi-Expression Programming (MEP) was introduced by Fallahpour et al. (2015). A supplier selection problem of a textile company was solved by the model proposed.

Many researchers applied the AHP to solve MCDM problems. For example, Sabiruddin et al. (2013) considered a gas metal arc welding process to derive an appropriate set of process parameters. Experimental results were analyzed and optimized value of process parameters were selected using the AHP. Choudhury et al. (2015) conducted several experiments on surface grinding to get the appropriate grinding condition. They applied the AHP successfully to evaluate the optimal grinding condition to obtain the best grinding performance.

TOPSIS method was also employed to find out solutions to a host of problems. Wang and Xin (2011) established a model of Absolute Analysis to evaluate the site of a thermal power plant. This model was solved by a multi-criteria decision making technique which is known as TOPSIS (Technique for Order Preference by Similarity to Ideal Solution). Different evaluating criteria were introduced to form the normalized weighted matrix. A suitable site was selected from the weighted data. Huang (2012) developed an evaluation based model to solve the performance of an electric power supply bureau of Chonging City, China. Various data such as cost of power supply, volume of power supply, current assets, etc. were collected from eight electric power supply bureaus. The ranking was done by TOPSIS method. Zhu et al. (2012) described the quality credit issue on different organizations such as food enterprises, academic institutes, corporate, etc. Different evaluation criteria were selected for the air conditioning market. The selection was done by TOPSIS method. Organ (2013) applied the TOPSIS method to choose the best private teaching institution for high school students. Ertugrul and Oztas (2014) presented the Fuzzy Logic concept to select the most economic mobile line and to achieve the business needs. Finally, the suitable mobile lines were selected by TOPSIS method.

The major issues in a supply chain like supplier selection problem can be solved by TOPSIS method. Eleren and Yilmaz (2011) applied the TOPSIS approach to select the best supplier for a textile firm in Turkey. Initially Fuzzy matrix was constructed with preferential judgment of all the criteria against different suppliers. Afterwards, TOPSIS method was applied to get the optimum result. Shahroudi et al. (2012) described the application of TOPSIS method for supplier selection in the case of an auto supply chain.


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The supplier selection was done based on some effective criteria and alternatives. Sharma and Jayaswal (2015) proposed a methodology of supplier selection using TOPSIS approach. Different criteria were selected to ensure good coordination between management and suppliers of an automobile industry. Weights were given to the criteria by the different experts. Finally, ranks of suppliers were obtained or the best supplier was chosen with proper implementation of TOPSIS methodology.

Considering the effectiveness of the AHP and TOPSIS methods, the combination of these two have been applied by many with success. This method is basically a hybrid method. Ghosh (2011) evaluated the faculty performance of an educational institution by multi-criteria decision making technique. Initially, different attributes of teachers were described. The AHP was applied to find the overall weight of teachers. After that, TOPSIS was applied to rank the best teacher. Bhutia and Phipon (2012) applied the AHP and TOPSIS method for a supplier selection problem. Both the quantitative and qualitative analyses were done to select the best supplier among all the suppliers considered. Jingfei et al. (2013) established the status evaluation index system of traffic crowding. The best traffic management system was selected by the AHP-TOPSIS method. Mansor et al. (2014) described the requirement of sustainable materials for an automotive parking brake lever component. The four basic criteria were introduced towards the selection of optimal hybrid composite materials for the automotive component. The selection process was done by integrated AHP-TOPSIS technique. The integrated technique was enabled to implement the systematic comparison between the designers of composite materials also.

## 3. Introduction to a case study for selecting green suppliers

This paper enumerates the selection process of an appropriate supplier of a pump manufacturing organization which can ensure supply of environmentally-friendly inventory items in the least amount of time. The manufacturing unit is located in a crowded city of West Bengal, India. Axial flow pumps, mixed flow pumps, centrifugal pumps, submersible pumps, etc. are produced by the organization. These products are highly employed in different water supply projects. Here, green supplier selection is necessary for environmental sustainability in the supply chain as well as in the production system. Supplier selection criteria are based on green purchasing, i.e. purchasing of environmentally-friendly components, consumables, etc. of a pump manufacturing organization. In the case of the pump manufacturing organization, green purchasing of inventory items include:

a) Centrifugal pump housing made by cast iron;
b) Ball bearings implementing advanced lubrication technology;
c) Impeller made by Poly Phenylene Oxide (PPO) plastic;
d) Rubber components made by recycled elastomers;
e) Vegetable oil, grease;
f) Motor and electrical items that consume less energy;
g) Pipes made by copper, cast iron, galvanized steel, cross-linked Polyethylene Tubing;
h) Wooden case packing, etc. that is environmentally friendly, reusable and recyclable.


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The slow rate of oxidation of cast iron materials reduces waste generation. The products made by cast iron are also recyclable. So, the centrifugal pump housing made of cast iron is environmentally-friendly and may be preferred. Ball bearings lubricated by bio-degradable vegetable oil or something similar are preferable and should be included in the green supply chain to promote an environmentally sustainable production system. Poly Phenylene Oxide (PPO) plastic has different properties including corrosion resistance, low pH level, recyclability, reusability, etc. Normally, the PPO plastic can be treated as a green component for impeller. Different spare parts for horizontal and vertical pumps like the piston ram, pipe end rings, pump seals, relief valves, etc. made by elastomers can be procured as eco-friendly inventory items. The motors that accord higher efficiency are desirable for less energy consumption. Rewinding of motors is done in order to avoid higher energy consumption. Power consumption in the pump manufacturing industry can be minimized by using capacitors and sleep power recovery systems. The pipes and tubes in different dimensions are used in industrial pumps as well as domestic pumps. Pipes and tubes can be made of such metals, plastics and other composite materials that ensure biodegradability, and should have corrosion resistance. Moreover, the procured inventory items in a green supply chain need to be cost efficient in addition to having these green properties.

Table 1
Description of criteria

| **Criterion** | **Criterion name** |
|---|---|
| $C_1$ | Percentage consumption of eco-friendly raw material |
| $C_2$ | Percentage consumption of finished goods material |
| $C_3$ | Waste generation |
| $C_4$ | Energy consumption |
| $C_5$ | Recyclability of inventory items |
| $C_6$ | Reusability of inventory items |
| $C_7$ | Cost |
| $C_8$ | Lead Time |

High percentage consumption of eco-friendly raw materials and finished goods is essential to assure the purpose of Green Purchasing. Waste generation should be minimized to obtain a pollution free environment. Low energy consumption, recyclability and reusability of inventory items consume minimum resources that are required to obtain a cost effective green production system. The major issues like minimum purchasing cost and shortest possible lead time of inventory items are taken into consideration to ensure increased productivity as well as minimum production cost.

To implement a green supply chain management system, the suppliers should be assessed based on some attributes or criteria (given in Table 1), which are related to environmental issues besides other criteria. These five suppliers are selected by the purchase manager and experts of the organization based on the procedure of tendering. Different criteria are introduced to ensure the environmentally friendly and cost effective supply chain. The authors have chosen these criteria based on discussions with some experts of the organization. The description of different suppliers against the attributes is given in Table 2.


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Table 2
Description of different criteria for different suppliers

| Supplier / Attribute | M | N | O | P | Q |
|---|---|---|---|---|---|
| C1 | High | Moderate | Some | Very low | High |
| C2 | Low | High | Very low | Some | Moderate |
| C3 | High | Moderate | High | Some | Very low |
| C4 | Low | Moderate | Huge | High | Moderate |
| C5 | Very high recyclable items | Some recyclable items | Very less recyclable items | Some recyclable items | Almost no recyclable items |
| C6 | Very high reusable items | Moderately reusable items | Low reusable items | High reusable items | Very less reusable items |
| C7 | Very high cost of inventory items | Very low raw material cost | Moderate raw material cost | High cost of inventory items | Very low cost of inventory items |
| C8 | shortest possible time period | Moderate | Moderate | Very high | Very high and not having any exact time period |

## 4. Hybrid AHP-TOPSIS technique for evaluation of appropriate supplier

Supplier selection is a common issue in the research. The selection may be done by different Multi-Criteria Decision Making (MCDM) techniques, such as, Analytic Hierarchy Process (AHP), Analytical Network Process (ANP), Simple Additive Weights (SAW) Method, Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Elimination Et Choice Translating Reality (ELECTRE), Preference Ranking Organization Method (PROMETHEE), etc. In this work, a hybrid AHP-TOPSIS model is applied for the selection process.

### 4.1 Application of the AHP for evaluating weights of suppliers

To select the green supplier for a pump manufacturing organization, eight different criteria are considered as listed in Table 1. The priorities of different criteria are proposed by the authors after discussions with the decision makers of the company, and presented by the nine point scale of AHP. In this hierarchical structure, supplier M, N, O, P and Q are chosen as the alternatives. Performances of alternatives are analyzed with respect to eight criteria chosen. The hierarchy structure is shown in Figure 1.

Let one consider matrix A.

For a matrix, $Aw= \lambda_{max}w$ (1)

Where, $w = (w_1,w_2,w_3,..)^T$ and $\lambda max \geq n$, when $\lambda max$ is the largest eigen value of the matrix A.


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On the other hand, for a consistent matrix, Aw = nw. (2)

For an inconsistent matrix, the degree of inconsistency is measured by Consistency Ratio (CR).

$$CR = (\lambda_{max} - n) / (n - 1) \quad (3)$$

In the present work, $a_{jk}$ represents the preference of $j_{th}$ criterion over $k_{th}$ criterion. $a_{ik}$ represents the preference of $i_{th}$ alternative over $k_{th}$ alternative.

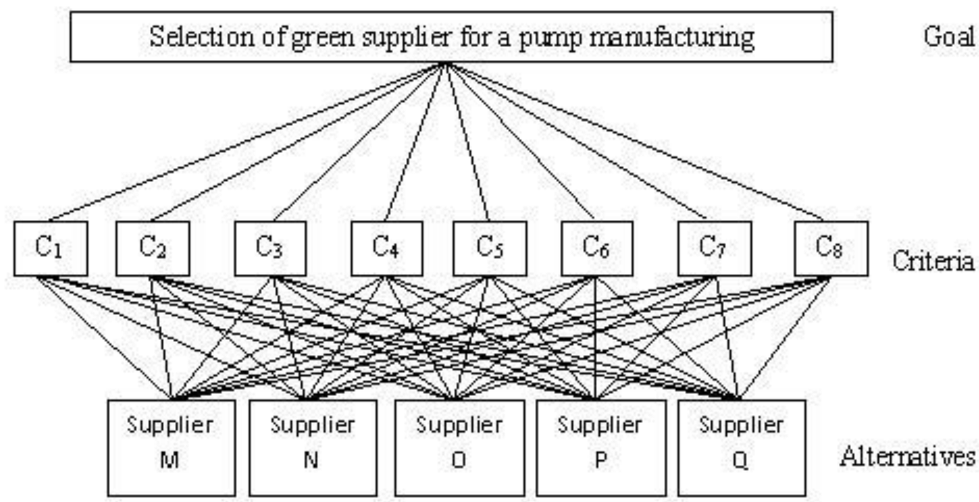


Figure1. Hierarchy structure

Normalized priorities or priority vectors for a criteria and alternative matrix are determined by Equations (4) and (5).

$$W_p = R_{ij} / \sum_{j=1}^{m} R_{ij} \quad (4)$$

where, $R_{ij} = \sum_{j=1}^{m} a_{jk}$; wherein is the number of criteria.

$$W_q = R_{ij} / \sum_{i=1}^{n} R_{ij} \quad (5)$$

when, $R_{ij} = \sum_{i=1}^{n} a_{ik}$; where n is the number of alternatives.


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Table 3
Criteria Matrix

| Selection of supplier | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ | $C_7$ | $C_8$ | Priority Vector |
|---|---|---|---|---|---|---|---|---|---|
| $C_1$ | 1 | 1/3 | 1/4 | 6 | 4 | 4 | 3 | 5 | 0.196 |
| $C_2$ | 3 | 1 | 1/3 | 3 | 4 | 4 | 1/2 | 2 | 0.148 |
| $C_3$ | 4 | 3 | 1 | 4 | 3 | 6 | 6 | 5 | 0.265 |
| $C_4$ | 1/6 | 1/3 | 1/4 | 1 | 1/3 | 1/4 | 1/2 | 3 | 0.0484 |
| $C_5$ | 1/4 | 1/4 | 1/3 | 3 | 1 | 4 | 3 | 5 | 0.14 |
| $C_6$ | 1/4 | 1/4 | 1/6 | 4 | ¼ | 1 | 2 | 4 | 0.099 |
| $C_7$ | 1/3 | 2 | 1/6 | 2 | 1/3 | 1/2 | 1 | 3 | 0.077 |
| $C_8$ | 1/5 | 1/2 | 1/5 | 1/3 | 1/5 | 1/4 | 1/3 | 1 | 0.025 |
| $\lambda_{max}$ = 9.779, CR = 0.02 | | | | | | | | | |

The Criteria Matrix is formed to solve the supplier selection problem. Table 3 shows the preferential comparison of different criteria. Consumption of raw material ($C_1$) is more preferred than finished goods ($C_2$), as raw material is consumed in larger quantities than finished goods in the case of the pump manufacturing organization. Less waste generation is most preferable for an environmentally friendly supply chain and inventory. Energy consumption is a less preferable criterion than material consumption. Different electrical items used in a pump manufacturing organization consume maximum energy in the case of manufacturing and test run of a pump. Recyclability ($C_5$) and reusability ($C_6$) of inventory items are moderately important criteria compared with the eco-friendly material consumption as different parts of a pump are not recyclable and reusable. To obtain the environmentally friendly supply chain, the cost involved should be as low as possible, but it has moderate importance compared to the criteria of material consumption and less waste generation. In this context, lead time ($C_8$) should be the least preferred criterion compared to the others. Generally, optimum lead time is required for a supply chain. In the case of a pump manufacturing organization, less waste generation ($C_3$) is highly desirable for improving green performance. Hence, it is more preferable than the other criteria mentioned in Table 1.

With these considerations, priority vectors or priority weights of the criteria matrix are computed by Equation 4. The maximum Eigen value and consistency ratio of this matrix are calculated by Equation 3. The desirable consistency ratio is always less than 10% which indicates acceptable consistency of the matrix.


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Table 4
Pair-wise comparison matrix for alternatives for criterion $C_1$

| $C_1$ | M | N | 0 | P | Q | Normalized Priorities |
|---|---|---|---|---|---|---|
| M | 1 | 3 | 4 | 6 | 2 | 0.353 |
| N | 1/3 | 1 | 1/5 | 2 | 1/6 | 0.081 |
| O | 1/4 | 5 | 1 | 3 | 1/2 | 0.215 |
| P | 1/6 | ½ | 1/3 | 1 | 1/4 | 0.049 |
| Q | 1/2 | 6 | 2 | 4 | 1 | 0.298 |
| $\lambda_{max}$ = 5.381 , CR = 0.085 | | | | | | |

Table 4 shows the pair-wise comparison matrix related to different suppliers with respect to the criterion, percentage consumption of eco-friendly raw material ($C_1$). Supplier M supplies a high quantity of environmentally friendly raw material. Supplier Q is also capable enough to supply a high quantity of eco-friendly raw material, but of a relatively less quantity compared with supplier M. Supplier Q is less preferable with respect to this criterion. With respect to these judgments, the normalized priorities or weights are assigned to each element of this matrix.

Table 5
Pair-wise comparison matrix for alternatives for criterion $C_2$

| $C_2$ | M | N | 0 | P | Q | Normalized Priorities |
|---|---|---|---|---|---|---|
| M | 1 | 1/5 | 2 | 1/3 | 1/2 | 0.0951 |
| N | 5 | 1 | 3 | 3 | 2 | 0.3302 |
| O | 1/2 | 1/3 | 1 | 1/5 | 1/6 | 0.0518 |
| P | 3 | 1/3 | 5 | 1 | 1/3 | 0.2279 |
| Q | 2 | 1/2 | 6 | 3 | 1 | 0.2948 |
| $\lambda_{max}$ = 5.419 , CR = 0.093 | | | | | | |

Table 5 shows pair-wise comparison of different suppliers with respect to criterion $C_2$, i.e. percentage consumption of eco-friendly finished goods material. Supplier N has more preference for a supply of environmentally friendly finished goods than other suppliers. The supplier Q is also more desirable for high consumption of the finished goods than supplier P, M and O respectively, but less desirable than supplier N.

In the same way, a pair-wise comparison matrix has been constructed for criterion, $C_3$ as shown in Table 6. The amount of waste generation ($C_3$) is quite less in the case of the items procured from supplier Q. The procured items from supplier Q are more desirable than that from other suppliers with respect to this criterion. The items from supplier N are desirable for low waste generation, but less desirable than supplier Q. Supplier M is the most undesirable of the other suppliers as the procured items from this supplier have quite a high waste generation capacity.


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Table 6
Pair-wise comparison matrix for alternatives for criterion $C_3$

| $C_3$ | M | N | 0 | P | Q | Normalized Priorities |
|---|---|---|---|---|---|---|
| M | 1 | 1/5 | ½ | 1/3 | 1/6 | 0.048 |
| N | 5 | 1 | 4 | 2 | 1/2 | 0.276 |
| O | 2 | 1/4 | 1 | 1/3 | 1/6 | 0.082 |
| P | 3 | 1/2 | 3 | 1 | 1/4 | 0.171 |
| Q | 6 | 2 | 6 | 4 | 1 | 0.42 |
| $\lambda_{max}$ = 5.106 , CR = 0.023 | | | | | | |

Table 7
Pair-wise comparison matrix for alternatives for criterion $C_4$

| $C_4$ | M | N | 0 | P | Q | Normalized Priorities |
|---|---|---|---|---|---|---|
| M | 1 | 3 | 7 | 2 | 3 | 0.361 |
| N | 1/3 | 1 | 6 | 2 | 4 | 0.3 |
| O | 1/7 | 1/6 | 1 | 1/3 | 1/4 | 0.042 |
| P | ½ | ½ | 3 | 1 | 2 | 0.157 |
| Q | 1/3 | ¼ | 4 | ½ | 1 | 0.137 |
| $\lambda_{max}$ = 5.261 , CR = 0.011 | | | | | | |

Table 8
Pair-wise comparison matrix for alternatives for criterion $C_5$

| $C_5$ | M | N | 0 | P | Q | Normalized Priorities |
|---|---|---|---|---|---|---|
| M | 1 | 4 | 6 | 4 | 7 | 0.403 |
| N | 1/4 | 1 | 3 | 3 | 8 | 0.279 |
| O | 1/6 | 1/3 | 1 | ¼ | 2 | 0.068 |
| P | 1/4 | 1/3 | 4 | 1 | 6 | 0.212 |
| Q | 1/7 | 1/8 | 1/2 | 1/6 | 1 | 0.035 |
| $\lambda_{max}$ = 5.39 , CR = 0.013 | | | | | | |

Less energy consumption is a more preferable criterion in the case of Green Manufacturing as well as Green Supply Chain Management. Supplier M is more accepted than other suppliers with respect to the criterion $C_4$ as the incurred products from this supplier consume less energy. Supplier N is less preferable than supplier M considering this attribute. Supplier P and Q are moderately preferred, but supplier O is very less preferred with respect to this criterion. The comparison of different suppliers, which is analyzed based on criterion $C_4$, is represented in Table 7.

Table 8 describes the comparison of different suppliers with respect to criterion $C_5$, i.e. Recyclability of inventory items. Supplier M can deliver highly recyclable items compared to the other suppliers, and hence, assigned more weight. The items that may be


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supplied by supplier N have high recyclability also. Supplier Q supplies the items which have low recyclability.

Table 9
Pair-wise comparison matrix for alternatives for criterion $C_6$

| $C_6$ | M | N | 0 | P | Q | Normalized Priorities |
|---|---|---|---|---|---|---|
| M | 1 | 3 | 5 | 2 | 6 | 0.329 |
| N | 1/3 | 1 | 5 | 3 | 6 | 0.297 |
| O | 1/5 | 1/5 | 1 | 1/3 | 4 | 0.111 |
| P | 1/2 | 1/3 | 3 | 1 | 7 | 0.229 |
| Q | 1/6 | 1/6 | 1/4 | 1/7 | 1 | 0.032 |
| $\lambda_{max}$ = 5.434 , CR = 0.017 | | | | | | |

Table 10
Pair-wise comparison matrix for alternatives for criterion $C_7$

| $C_7$ | M | N | 0 | P | Q | Normalized Priorities |
|---|---|---|---|---|---|---|
| M | 1 | 1/6 | 1/4 | 1/3 | 1/7 | 0.035 |
| N | 6 | 1 | 3 | 6 | 4 | 0.38 |
| O | 4 | 1/3 | 1 | 4 | 1/2 | 0.187 |
| P | 3 | 1/6 | 1/4 | 1 | 1/6 | 0.087 |
| Q | 7 | 1/4 | 2 | 6 | 1 | 0.309 |
| $\lambda_{max}$ = 5.397, CR = 0.089 | | | | | | |

Table 11
Pair-wise comparison matrix for alternatives for criterion $C_8$

| $C_8$ | M | N | 0 | P | Q | Normalized Priorities |
|---|---|---|---|---|---|---|
| M | 1 | 3 | 3 | 6 | 7 | 0.368 |
| N | 1/3 | 1 | 2 | 6 | 6 | 0.28 |
| O | 1/3 | 1/2 | 1 | 5 | 6 | 0.234 |
| P | 1/6 | 1/6 | 1/5 | 1 | 3 | 0.083 |
| Q | 1/7 | 1/6 | 1/6 | 1/3 | 1 | 0.032 |
| $\lambda_{max}$ = 5.327 , C.R = 0.0122 | | | | | | |

A pair-wise comparison matrix of different suppliers for criterion $C_6$ is established and is shown in Table 9. The reusable capacity is high in the case of items procured from supplier M, and is to be mostly favored. The reusable capacity is also high for the items procured from suppliers N and P respectively, but their capacities are less than the procured items from supplier M. Therefore, weights assigned to them are lower than that of supplier M. The supplier Q can supply the items with low reusability, and hence, is not much favored in this work considering due focus given on environmental friendliness and the use of measures causing less disturbance on the environment.


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Table 10 indicates a pair-wise comparison matrix of different suppliers with respect to the criterion $C_7$, i.e. purchasing cost. The stock items procured from the suppliers N and Q are cost effective, i.e. purchasing costs are less than the other suppliers, and they are assigned more weights. Moderate costs are needed for procured items from supplier O, and they are given moderate weight. The items procured from supplier M are costlier than others. As they are not cost effective, less weight is assigned to them.

Minimum lead time is a necessity for purchasing products to achieve reduced manufacturing lead time. In this context, the lead time is minimal for purchasing products from supplier M and N respectively. Supplier Q supplies eco-friendly products, but the lead time is higher than the other suppliers. So, low weight is assigned to it. Table 11 is constructed to compare the suppliers according to their performances over lead time.

**4.2 Application of TOPSIS for selecting the appropriate suppliers**

Here, the TOPSIS method is used for ranking the suppliers. The best supplier is chosen to obtain a Green Supply Chain Management system of a pump manufacturing organization.

In this context, n= 5 suppliers should be evaluated and each supplier has m= 8 criteria. An element of the matrix, $x_{ij}$ is the $j^{th}$ criterion value of the $i^{th}$ supplier, and the matrix is shown in Table 12.

First, the decision matrix is normalized.

$$r_{ij} = x_{ij} / \sqrt{\sum_{i=1}^{n} x_{ij}^2}, \quad i= 1, \ldots, n; \; j= 1, \ldots, m. \qquad (6)$$

The normalized values of composite matrix and supplier's priority against criteria are represented by $r_{ij}$ and $x_{ij}$ respectively.

$$V_{ij} = W_i r_{ij}, \quad i= 1, \ldots, n; \; j= 1, \ldots, m. \qquad (7)$$

where, the weighted normalized value of $j^{th}$ criterion against $i^{th}$ supplier is represented by $V_{ij}$.

$$\text{Positive Ideal Solution } (A^+) = \{v_j^+, \; j= 1, \ldots, m\} \qquad (8)$$

$$\text{Negative Ideal Solution } (A^-) = \{v_j^-, \; j= 1, \ldots, m\} \qquad (9)$$

$v_j^+ = \max\{v_{ij}, \; i= 1, \ldots, n\}$ , $v_j^- = \min\{v_{ij}, \; i= 1, \ldots, n\}$, where, j is the benefit criteria.

The distance from the $i^{th}$ supplier to the Positive Ideal Solutions and the distance from the $i^{th}$ supplier to the Negative Ideal Solutions are represented by $S_i^+$ and $S_i^-$ respectively, and they are given by:

$$S_i^+ = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^+)^2}, \quad i = 1, \ldots, n \qquad (10)$$


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$S_i^- = \sqrt{\sum_{j=1}^{m}(v_{ij} - v_j^-)^2}$, i = 1, ….., n (11)

Next, $C_i$, the Quality Credit score or ideal solution, is calculated following Equation 12.

$C_i = \frac{S_i^-}{S_i^- + S_i^+}$, i = 1, ….., n (12)

The normalized priorities for all suppliers with respect to different criteria are determined by Equation 6 and presented in Table 12. This table represents the Decision Matrix which is required for initiating the TOPSIS method.

Table 12
Composite vector of distributive mode for TOPSIS

| Weight | 0.196 | 0.148 | 0.265 | 0.0484 | 0.141 | 0.099 | 0.077 | 0.025 |
|---|---|---|---|---|---|---|---|---|
| Supplier | A | B | C | D | E | F | G | H |
| M | 0.353 | 0.095 | 0.048 | 0.361 | 0.403 | 0.329 | 0.035 | 0.368 |
| N | 0.081 | 0.33 | 0.276 | 0.3 | 0.279 | 0.297 | 0.38 | 0.28 |
| O | 0.215 | 0.051 | 0.082 | 0.042 | 0.068 | 0.011 | 0.187 | 0.234 |
| P | 0.049 | 0.227 | 0.171 | 0.157 | 0.212 | 0.229 | 0.087 | 0.083 |
| Q | 0.298 | 0.294 | 0.42 | 0.137 | 0.035 | 0.032 | 0.309 | 0.032 |

Table 13
Square root values from the composite matrix

| Weight | 0.196 | 0.148 | 0.265 | 0.0484 | 0.141 | 0.099 | 0.077 | 0.025 |
|---|---|---|---|---|---|---|---|---|
| Supplier | A | B | C | D | E | F | G | H |
| M | 0.125 | 0.009 | 0.002 | 0.13 | 0.162 | 0.108 | 0.001 | 0.135 |
| N | 0.006 | 0.109 | 0.076 | 0.09 | 0.078 | 0.088 | 0.144 | 0.078 |
| O | 0.046 | 0.002 | 0.006 | .001 | 0.004 | 0.012 | 0.035 | 0.055 |
| P | 0.002 | 0.051 | 0.029 | .024 | 0.045 | 0.052 | 0.007 | 0.006 |
| Q | 0.089 | 0.086 | 0.176 | .018 | 0.001 | 0.001 | 0.095 | 0.001 |
| Sum | 0.27 | 0.259 | 0.291 | 0.266 | 0.292 | 0.260 | 0.283 | 0.277 |
| Square Root | 0.519 | 0.509 | 0.54 | 0.516 | 0.54 | 0.510 | 0.532 | 0.526 |

Table 14
Normalized decision matrix

| Weight | 0.196 | 0.148 | 0.265 | 0.0484 | 0.141 | 0.099 | 0.077 | 0.025 |
|---|---|---|---|---|---|---|---|---|
| Supplier | A | B | C | D | E | F | G | H |
| M | 0.68 | 0.186 | 0.089 | 0.699 | 0.746 | 0.645 | 0.065 | 0.699 |
| N | 0.157 | 0.648 | 0.511 | 0.582 | 0.517 | 0.582 | 0.713 | 0.531 |
| O | 0.414 | 0.101 | 0.153 | 0.082 | 0.127 | 0.217 | 0.351 | 0.445 |
| P | 0.095 | 0.447 | 0.317 | 0.305 | 0.392 | 0.449 | 0.163 | 0.158 |
| Q | 0.574 | 0.578 | 0.77 | 0.265 | 0.065 | 0.063 | 0.58 | 0.062 |


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Table 15
Weighted normalized decision matrix

| Weight | 0.196 | 0.148 | 0.265 | 0.0484 | 0.141 | 0.099 | 0.077 | 0.025 |
|---|---|---|---|---|---|---|---|---|
| Supplier | A | B | C | D | E | F | G | H |
| M | 0.1334 | 0.027 | 0.024 | 0.034 | 0.105 | 0.063 | 0.005 | 0.017 |
| N | 0.03 | 0.096 | 0.136 | 0.028 | 0.072 | 0.057 | 0.055 | 0.013 |
| O | 0.081 | 0.015 | 0.04 | 0.003 | 0.017 | 0.021 | 0.027 | 0.011 |
| P | 0.018 | 0.066 | 0.084 | 0.014 | 0.055 | 0.044 | 0.012 | 0.003 |
| Q | 0.112 | 0.086 | 0.206 | 0.012 | 0.009 | 0.006 | 0.044 | 0.001 |

The summation values of squared normalized priorities with respect to different weights (Priority Vector) and the square root of the summed values are shown in Table 13. Calculated normalized values of the Decision Matrix are presented in Table 14. The calculations are done using Equation 6.

Table 16
Determination of distance from positive ideal solution

| Supplier | A | B | C | D | E | F | G | H | $S_i^+$ |
|---|---|---|---|---|---|---|---|---|---|
| M | 0 | 0.0047 | 0.0332 | 0 | 0 | 0 | 0.0024 | 0 | 0.201 |
| N | 0.0102 | 0 | 0.0049 | 0.00003 | 0.001 | 0.00003 | 0 | 0.00001 | 0.1279 |
| O | 0.0027 | 0.0065 | 0.0274 | 0.0008 | 0.0076 | 0.0017 | 0.0007 | 0.00003 | 0.2185 |
| P | 0.0131 | 0.0008 | 0.0149 | 0.0003 | 0.0024 | 0.0003 | 0.0017 | 0.0002 | 0.1846 |
| Q | 0.0004 | 0.0001 | 0 | 0.0004 | 0.0092 | 0.0032 | 0.0001 | 0.00026 | 0.1174 |

The weighted normalized values of the suppliers are computed by Equation 7. The values with respect to eight criteria are shown in Table 15. The Positive Ideal Solutions of eight criteria are determined using Equation 8. The distance between the Positive Ideal solutions and each supplier is computed by Equation 10 and is presented in Table 16.


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Table 17
Determination of distance from negative ideal solution

| Supplier | A | B | C | D | E | F | G | H | $S_i^-$ |
|---|---|---|---|---|---|---|---|---|---|
| M | 0.0131 | 0.0001 | 0 | 0.0008 | 0.0092 | 0.0032 | 0 | 0.0002 | 0.1709 |
| N | 0.0001 | 0.0066 | 0.0119 | 0.0005 | 0.004 | 0.0026 | 0.0024 | 0.0001 | 0.1708 |
| O | 0.0039 | 0 | 0.00028 | 0 | 0.00007 | 0.0002 | 0.0004 | 0.0001 | 0.0712 |
| P | 0 | 0.0026 | 0.0036 | 0.0001 | 0.0092 | 0.0014 | 0.00005 | 0.000004 | 0.1306 |
| Q | 0.0088 | 0.005 | 0.0332 | 0.00007 | 0 | 0 | 0.0015 | 0 | 0.2206 |

The Negative Ideal Solutions of eight criteria are obtained by Equation 9. The distance between the Negative Ideal Solutions and each supplier is calculated by Equation 11 and presented in Table 17.

Table 18
Quality credit score for supplier ranking

| Supplier | Ideal Solution | Rank |
|---|---|---|
| M | 0.4595 | 3 |
| N | 0.5718 | 2 |
| O | 0.2459 | 5 |
| P | 0.4144 | 4 |
| Q | 0.6526 | 1 |

The ideal solutions or final scores for all suppliers are described in Table 18. The ranking of green suppliers are analyzed with these scores which are computed by the Equation 12.

## 5. Results and discussion

Rank of the supplier is determined in this work by the hybrid AHP-TOPSIS technique. The rank is finally obtained by quality credit score or ideal solution which is described in Table 18. The preference of suppliers was determined in this chronological order; i.e. supplier Q> N > M > P > O. Supplier Q is the most preferred to obtain a Green Supply Chain Management system as well as Green Manufacturing system in this work. Supplier Q supplies a very large quantity of environmentally friendly raw material inventory items which are described in Table 1. Some environmentally friendly materials of finished goods are also consumed from supplier Q so that waste generation will be less. The energy consumption by these items is of moderate quantity as shown in Table 1. These items are not recyclable, or quite a lesser quantity of them are reusable. The inventory costs of these items are quite low, but the lead time is too high. Supplier N supplies moderate quantities of environmentally friendly raw materials and the waste generation is moderate. Items supplied by supplier N are moderately recyclable, or reusable, and the


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lead time is moderate. The raw material cost is quite low for the products delivered by supplier N. Supplier O is less preferable as the items delivered by this supplier are not suitable for Green Manufacturing.

From the results, it is shown that high preference is given for low waste generation and low inventory cost. Reusability or recyclability has moderate importance on green supplier selection for the pump manufacturing industry considered. It is observed that selection of green supplier leads to green inventory, and minimum waste generation.

## 6. Conclusion

From the work presented in this article, the following conclusions may be made. The pump manufacturing organization considered in this work is located in a crowded city of Eastern India, and it plans to select an eco-friendly supplier whose aim is sustainability of the environment and cost minimization of inventory items. In this context, the selection of a supplier is made by a Hybrid AHP-TOPSIS technique. It enables the organization to find the best suited supplier among those considered. The selected supplier fulfills different criteria which are favorable for the green supply chain management. Selection of this green supplier is likely to promote optimal green inventory. Thus, it can be stated that the hybrid method adopted using the AHP and TOPSIS is well suited for evaluating the optimal selection of a green supplier considering eco-friendliness of the system.

Suppliers should be aware about environmental issues, and they need to promote green supply chain and green sustainable manufacturing systems. Proper decision making is therefore needed to select green suppliers for this kind of manufacturing unit.

This paper does not consider the amount of inventory items, energy consumption, purchasing costs and lead time of inventory items. Future works are required to consider all these points to solve the supplier selection problem over a wider perspective.

Further investigation may also be made with different real life case studies related to a different manufacturing industry using the AHP-TOPSIS hybrid algorithm or other multi criteria decision making techniques.


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## REFERENCES

Afshari, A., Mojahed, M. & Yusuff, R.M. (2010). Simple additive weighting approach to personnel selection problem. *International Journal of Innovation, Management and Technology, 1(5),* 511-515. URL: ijimt.org/papers/89-M474.pdf

Aouadni, S. & Rebai, A. (2013). Inventory management with supplier selection problem: Supply uncertainty. *Proceedings of the International Conference on Modeling, Simulation and Applied Optimization, 10,* 1-5. doi: 10.1109/ICMSAO.2013.6552577

Bayazit, O., Karpak, B. & Yagc, A. (2006).A purchasing decision: Selecting a supplier for a construction company. *Journal of Systems Science and Systems Engineering, 15(3),* 217-231. doi: 10.1007/s11518-006-5009-3

Bhutia, P.W. & Phipon, R. (2012). Application of AHP and TOPSIS method for supplier selection problem. *IOSR Journal of Engineering, 2(10),* 43-50. URL: www.iosrjen.org/Papers/vol2_issue10%20(part-3)/F021034350.pdf

Chaudhury, A., Mandal, B. & Das, S. (2015). Selection of appropriate fluid delivery technique for grinding titanium grade-1 using the analytic hierarchy process. *International Journal of Analytic Hierarchy Process, 7(3),* 454-469. doi: http://dx.doi.org/10.13033/ijahp.v7i3.356

Dragincic, J. & Vranesevic, M. (2014). AHP-based group decision making approach to supplier selection of irrigation equipment. *International Journal of Water Resources Development: Economic and Legal Aspects, 41(6),* 782-791. doi: 10.1134/S0097807814060050

Eleren, A. & Yilmaz, C. (2011). Selection of suppliers by fuzzy TOPSIS model; sample study from Turkey. *International Journal of Business and Social Science, 2(22),* 189-200.

Ertugrul, I. & Oztas, T. (2014). Business mobile-line selection in Turkey by using fuzzy TOPSIS, one of the multi-criteria decision methods. *Second International Conference on Information Technology and Quantitative Management, 31*, 40-47. doi:10.1016/j.procs.2014.05.243

Fontana, M.E. & Cavalcante, C.A.V. (2014). Use of PROMETHEE method to determine the best alternative for warehouse storage location assignment. *International Journal of Advanced Manufacturing Technology, 70(9),* 1615-1624. doi: 10.1007/s00170-013-5405-z

Fallahpour, A., Olugu, E.U. & Musa, S.N. (2015). A hybrid model for supplier selection: integration of AHP and multi expression programming (MEP). *International Journal of Neural Computing and Application, 10,* 1-6. URL: link.springer.com/content/pdf/10.1007%2Fs00521-015-2078-6.pdf


*ISSN 1936-6744*
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Galankashi, M.R., Chegeni, A., Soleimanynanadegany, A., Memari, A., Anjomshoae, A., Helmi, S.A. & Dargi, A. (2015). Prioritizing green supplier selection criteria using fuzzy analytical network process. *Procedia of Global Conference on Sustainable Manufacturing, 26,* 689–694. doi: 10.1016/j.procir.2014.07.044

Ghosh, D.N. (2011). Analytic Hierarchy Process & TOPSIS method to evaluate faculty performance in engineering education. *Universal Journal of Applied Computer Science and Technology, 1,* 63-70. URL: www.ijesit.com/Volume%203/Issue%201/IJESIT201401_02.pdf

Huang, W. & Huang, Y.Y. (2012). Research on the performance evaluation of Chongqing electric power supply bureaus based on TOPSIS. *Energy Procedia, 14*, 899-905. doi: 10.1016/j.egypro.2011.12.1030

Jingfei, Y., Wang, L. & Gong, X. (2013). Study on the status evaluation of urban road intersections traffic congestion based on AHP-TOPSIS modal. *Proceedings of 13th COTA International Conference of Transportation Professionals, 96,* 609-616. doi: 10.1016/j.sbspro.2013.08.071

Kahraman, C., Cebeci, U. &Ulukan, Z. (2003). Multi-criteria supplier selection using fuzzy AHP. *Journal of Logistics Information Management, 16(6),* 382–394. http://dx.doi.org/10.1108/09576050310503367

Lee, A.H. I., Kang, H., Hsu, C. & Hung, H. (2009). A green supplier selection model for high-tech industry. *International Journal of Expert Systems with Applications, 36,* 7917–7927. doi: 10.1016/j.eswa.2008.11.052

Lei, D.X., Kumar, D.T., Shankar, M., Kannan, D. & Chen, G. (2013). Analyzing criteria and sub-criteria for the corporate social responsibility-based supplier selection process using AHP. *International Journal of Advanced Manufacturing Technology, 68(1),* 907-916. doi: 10.1007/s00170-013-4952-7

Mansor, M.R., Sapuna, S.M., Zainudin, E.S., Nuraini, A.A. & Hambali, A. (2014). Application of integral AHP-TOPSIS method in hybrid natural fiber composites materials selection for automotive parking brake lever component. *Australian Journal of Basic and Applied Sciences, 8(5),* 431-439. URL: www.ajbasweb.com/old/ajbas/2014/Special%202/431-439.pdf

Marinovic, J.S., Petkovic, M.D. & Stanimirovic, I.P. (2015). Application of the ELECTRE method to planetary gear train optimization. *Journal of Mechanical Science and Technology, 29(2),* 647-654. doi: 10.1007/s12206-015-0124-z

Organ, A. (2013). Practice over the private teaching institutions selection problem in one of secondary schools with using multiple attribute decision making method of TOPSIS. *Proceedings of the Second Cyprus International Conference on Educational Research, 89,* 489-495. doi: 10.1016/j.sbspro.2013.08.882

Saaty, T.L. (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology, 15,* 234-281. doi: 10.1016/0022-2496(77)90033-5

Saaty, T.L. (1990). Decision making by the analytic hierarchy process: Theory and applications. *European Journal of Operational Research, 48,* 9-26. URL: www.colorado.edu/geography/leyk/geog_5113/.../saaty_2008.pdf

Saaty, T.L. (2002). Decision making with analytic hierarchy process. *Scientia Iranica, 9,* 215-229. URL: www.colorado.edu/geography/leyk/geog_5113/.../saaty_2008.pdf

Sabiruddin, K., Bhattachariya, S. & Das, S. (2013). Selection of appropriate process parameters for gas metal arc welding of medium carbon steel specimen. *International Journal of Analytic Hierarchy Process, 5,* 252-267. http://dx.doi.org/10.13033/ijahp.v5i2.184

Shahroudi, K. & Tonekaboni, S.M.S.(2012). Application of TOPSIS method to supplier selection in Iran auto supply chain. *Journal of Global Strategic Management, 12,* 123-131. doi: 10.20460/JGSM.2012615779

Sharma, B. & Jayaswal, P. (2015). Supplier selection in manufacturing industry using TOPSIS method. *International Journal of Research in Engineering and Applied Sciences, 5(12),* 62-66.

Tahriri, F., Osman, M.R., Ali, A., Yusuff, R. M. & Esfandiary, A. (2008). AHP approach for supplier evaluation and selection in a steel manufacturing company. *Journal of Industrial Engineering and Management, 1(2),* 54-76. doi: http://dx.doi.org/10.3926/jiem..v1n2.p54-76

UmaDevi, K., Elango, C. & Rajesh, R. (2012). Vendor selection using AHP. *Proceedings of the International Conference on Modeling Optimization and Computing, 38,* 1946-1949. doi: 10.1016/j.proeng.2012.06.237

Wang, T. & Xin, B.C. (2011). Thermal power plant sitting based on TOPSIS method. *Procedia of Advances in Control Engineering and Information Science, 15,* 5384–5388. doi: 10.1016/j.proeng.2011.08.998

Zhu, X., Wang, F., Liang, C., Lia, J. & Sun, X. (2012). Quality credit evaluation based on TOPSIS: evidence from air-conditioning market in China. *Proceedings of theInternational Conference on Computational Science, 9,* 1256-1262. doi: 10.1016/j.procs.2012.04.137


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