# Operational excellence in a green supply chain for environmental management: A case study

KAZANCOGLU, Y <http://orcid.org/0000-0001-9199-671X>, SAGNAK, M <http://orcid.org/0000-0002-0799-0348>, KAYIKCI, Y <http://orcid.org/0000-0003-2406-3164> and KUMAR MANGLA, S <http://orcid.org/0000-0001-7166-5315>



**Published version**

KAZANCOGLU, Y, SAGNAK, M, KAYIKCI, Y and KUMAR MANGLA, S (2020). Operational excellence in a green supply chain for environmental management: A case study. Business Strategy and the Environment, 29 (3), 1532-1547.

Business Strategy and the Environment

ERP ENVIRONMENT

# Operational Excellence in a Green Supply Chain for Environmental Management - a Case Study



| | |
|---|---|
| Journal: | *Business Strategy and the Environment* |
| Manuscript ID | BSE-19-0453.R1 |
| Wiley - Manuscript type: | Research Article |
| Keywords: | Operational Excellence, Green Supply Chain, Performance Assessment, Sustainability, Fuzzy ANP, Weighted Scoring Method |
| | |

# Operational Excellence in a Green Supply Chain for Environmental Management - a Case Study


## Abstract

Nowadays, organizations have started to become more conscious about the environment in their supply chain operations. The greening process has guided supply chain practices into new ways of thinking according to green standards. The assessment of the performance of green supply chain management (GSCM) requires a holistic view for the whole supply chain. In this context, given that becoming green in the operational side of activities is essential, the performance assessment of operational activities also requires a holistic view to be taken. In this paper, an attempt has been made to improve the performance of GSCM by examining and evaluating the green operational excellence of a hot dip galvanizing company. The framework includes several green operational excellence key criteria; namely, Quality Management, Efficiency Management, Green Production/Manufacturing, Eco-Packaging and Green Design. Firstly, the weights of the criteria and the respective measurements were found by Fuzzy ANP. Then, the overall operational performance score was found by a Weighted Scoring Method. Finally, both managerial and theoretical implications were suggested according to the outcomes and findings of the case study.


**Key Words:** Operational Excellence; Green Supply Chain; Performance Assessment; Sustainability; Fuzzy ANP; Weighted Scoring Method

## 1. Introduction

Nowadays, strict regulations, high international competitiveness and pressure from stakeholders have obliged organizations to consider environmental issues in planning of their practices and their traditional supply chains (Zhu et al., 2008; Rivera, 2019). If green issues are not considered, unnecessary waste is created and ecological problems arise as a consequence (Zhu et al., 2008). Various factors, such as economic concerns, social responsibility and ethical issues have left companies no choice but to engage in environmental considerations (Hervani et al., 2005). For this reason, businesses have started to become more conscious about the environment in their supply chain activities in an effort to decrease or eliminate waste and protect natural resources (Min and Kim, 2012; Xie et al., 2019).

The term, green supply chain management (GSCM), has arisen as a strategical consideration aiming to increase economic advantage, decrease environmental impacts and enhance operational efficiency through reduction of resource use (Zhu and Sarkis, 2006). Organizations have started to put GSCM principles into practice in order to earn new market share, increase profits and gain competitive advantage by minimizing the environmental risks, while maximizing responsiveness (Lee et al., 2009).

GSCM is defined as a concept to include green concerns in supply chain activities such as design, purchasing, production, logistics, packaging, marketing, and reverse logistics. According to Kazancoglu et al. (2018), GSCM is an optimal balance of these activities. In a wider context, GSCM aims to decrease life cycle impacts of goods, use of resources and environmentally harmful materials in manufacturing operations, and environmental pollution

(Diabat et al., 2013). It also hopes to improve market share, brand image and economic performance (Daweiet al., 2015) through integrating supply chain activities with green concepts.

The assessment of GSCM performance requires a holistic view of the whole supply chain. GSCM performance can be appraised by inclusion of both qualitative and quantitative factors. Some organizations focus on financial issues such as profitability or return on investment (ROI); others concentrate more on operational measures such as service level, inventory decisions or quality of the product (Kazancoglu et al., 2018).

Since one of the critical issues regarding GSCM practices is in operations, becoming green in the operational side of the activities is very important. Operational performance can be defined as the ability to increase efficiency of production and delivery of high quality products while decreasing the inventory levels, scrap and need to rework (Zhu et al., 2008; Zhang and Yang, 2016; Geng et al., 2017). In addition, increasing flexibility facilitates customer satisfaction through interaction with customers. This flexibility together with service quality can be regarded as critical factors for improving operational performance (Diabat et al., 2013; Chavez et al., 2016).

In this paper, an operational excellence framework is proposed to improve GSCM performance. This is then applied to evaluate the operational performance of GSCM in a hot dip galvanizing company in Turkey. The framework includes five criteria; these are Quality Management, Efficiency Management, Green Production/Manufacturing, Eco-Packaging and Green Design. Firstly, the weights of the criteria and the respective measurements were established by Fuzzy ANP; the overall operational performance score was then calculated by a Weighted Scoring Method. The performance scores regarding each criterion were multiplied with the respective criterion weights in order to get the overall operational performance of the organization.

Following the introduction, Section 2 presents the related literature review on operational performance. Section 3 explains the framework itself and the need for a framework. Section 4 describes the method, Fuzzy ANP and weighted scoring method, respectively. Section 5 includes the case study and the results of the application. Section 6 details the theoretical and managerial implications and finally, Section 7 lists the concluding remarks and future research directions.

## 2. Literature Review

The systematic literature review approach suggested by Yadav and Desai (2016) is adopted to capture relevant articles for this literature review section. Initially, Scopus and Web of Science databases are utilized to retrieve data for operational performance in GSCM. Duplicated articles are then removed with those remaining being extensively reviewed. It was observed that operational performance with a greener focus has achieved significant importance in recent years, especially given the widening sustainable aims in industry, business and institutions (Azevedo et al. 2011; Yu et al., 2014; Chuang, 2014;). As defined by Kazancoglu et al. (2018), operational performance in GSCM refers to the degree that the company achieves to satisfy the needs of the customers through high production efficiency and delivery of products with high quality; but at the same time, decreasing inventory levels and inputs, as well as minimizing waste and scrap are seen as crucial (Zhu et al., 2008; Jabbour et al., 2015). This capability is a basic component to gain a competitive advantage for a company (Shang et al., 2010; Duarte et al., 2011; Yu et al., 2014; Gokarn and Kuthambalayan, 2019). Therefore, improved operational performance is central for the responsiveness of a company to increase market share and revenue growth (Aydiner et al., 2019). “Green” should include every stage of operational processes within the supply chain, connecting supplier from the raw material stage to the consumer, covering manufacturing, packaging and material handling (Shang et al., 2010). In order to improve operational performance, four criteria are identified for manufacturing companies; satisfaction of customers, supplier flexibility, communication with suppliers and service quality level (Diabat et al., 2013).

The level of a company’s overall environmental performance is inter-related with the operational performance of the company. (Younis et al., 2016). Moreover, today’s customers are much more environmentally conscious, pressuring companies to guarantee that their products and all related processes and activities are in line with rules and regulations to minimize their environmental impact (Sarkis, 2001; Srivastava, 2007). Many green concepts like eco-packaging, green manufacturing and green design appear as enablers for operational performance (Chuang, 2014; Farias et al., 2019b). Moreover, improving operational performance requires an organization's internal activities to be in place; these include environmentally friendly activities, green management with a holistic view and involvement of staff. External practices and activities must also be implemented - cooperation with stakeholders, recycling, reuse and recovery (Hanna et al., 2000; Gonzalez et al, 2008; Younis et al., 2016; Yu et al., 2017). Development of green products may not only bring competitive advantages and cost savings, but can also improve quality level and customer satisfaction with less scrap and rework rate (Diab et al., 2015). Implementation of pollution prevention practices and green design results in increased production efficiency by minimizing consumption of energy and decreasing fees on waste treatment and discharge (Jabbour and Jabbour, 2016). Therefore, the green product contributes to environmental performance very positively (Zhu et al., 2005). However, from an economic point of view, it has a relatively less positive effect (Lewis and Gretsakis, 2001). Green activities are adopted to achieve green products, to minimize emissions, pollution and to reduce the use of resources (Humphreys et al., 2003; Lee et al., 2009; Wu et al., 2015; Diab et al., 2015; Malviya and Kant, 2015). Adopting sustainable and green activities requires involvement of all supply chain participants (customers, suppliers), so that the entire chain becomes “greened”. Cooperation and collaboration become much easier and natural when everyone has the same goals (Zhu et al. 2008; Giovanni and Vinzi, 2012).

## 3. A Framework for Operational Excellence of GSCM Performance

In terms of greening processes, there are many criteria for assessing, evaluating and measuring operational performance that should be considered to lead to high impacts for companies. Choosing appropriate criteria involves both a literature review and consultation with experts from the industry (Wu et al., 2011). In current literature, different criteria have been examined from multiple studies based on production, material handling, logistics management and waste to assess operational performance in GSCM. Various authors categorize and classify different criteria to measure operational performance by applying different methodologies. Azevedo et al. (2011) provided a framework to show the most significant interactions among green performance and activities by using the criteria of customer satisfaction, efficiency, environmental cost, waste and quality. This was evaluated by adopting a case-study approach. Chuang (2014) defined operational performance with four factors, namely, green recycling, green packaging, green using and green manufacturing. In addition, these criteria are divided into nine main criteria and 43 sub criteria where an AHP-based model was used to assess the operational performance. Jabbour et al. (2015) proposed a framework to study relationships among green activities, operations and environmental performances using five criteria - green design, green procurement, environmental management, environmental collaboration with customers and recovery of investment; this was also evaluated by adopting a case-study methodology. Chaudharya and Chanda (2015) presented an ANP-based methodology to evaluate and measure the performance in GSCM using six criteria - eco design, green purchasing, internal environmental management system, green packaging, internal recovery and relations with customers. Sehnem et al. (2019) analyzed critical success factors for improving sustainable supply chain performance through operational excellence with the adoption of the circular economy. Gólcher-Barguil et al. (2019) presented the development of conceptual framework and mathematical formulations to measure operational excellence. Many examples can be given, but it is crucial to conceptualize which criteria will improve overall operational performance in GSCM. Therefore, there is a need to develop a framework.

In this research, five criteria, and 57 measurements are adopted to propose a framework to measure the operational performance in GSCM as seen in Table 1. Five criteria are listed as follows: Quality Management, Efficiency Management, Green Production / Manufacturing, Eco-Packaging and Green Design.

**[Table 1 Near Here]**

*3.1.Quality Management*

Increase in quality in terms of products and processes has a greater impact in improving operational performance (Zhu et al., 2008; Jabbour et al., 2015). Achieving less rejection rate (Azevedo et al., 2011), yield rate (Azevedo et al., 2011), defect rate (Diabat et al., 2013), rework rate (Henao et al., 2019), scrap rate (Zhu et al., 2005; Zhu et al., 2007) through better management practices will improve quality. Increase in quality as an ultimate criterion of operational performance has been addressed by various researchers (see Table 2).

*3.2.Efficiency Management*

Increasing efficiency is not an easy task but it has a great potential to reach a higher degree of operational performance (Duarte et al., 2011; Azevedo et al., 2011). Using environmentally friendly materials and machines can reduce overhead and operating expenses, improve capacity utilization and increase energy efficiency (Dubey et al., 2015; Tseng et al., 2019).

*3.3.Green Production/Manufacturing*

Green manufacturing criteria has been used to measure the operational performance by various researchers (see Table 2). Green manufacturing is characterized by manufacturing processes that have green resources as inputs while achieving outputs via less pollution, less waste and loss in production (Srivastava, 2007; Dubey et al., 2015) and production practices (i.e. lean, agile) for minimum energy and resource consumption (Sellitto et al. 2019; Shang et al., 2010). Green production/manufacturing aims to reduce the number of hazardous processes and machines (Zhu et al., 2007; Green et al., 2008; Zhu et al., 2008) and to use more recyclable and recycled materials in work practices (Chuang, 2014) to improve performance. Furthermore, green production/manufacturing is an important concept that may lead to competitive advantage by maximizing efficiency while producing quality of processes and outputs by minimizing cost. (Dubey et al., 2015).

### *3.4.Eco-Packaging*

Eco-packaging has been used as a criterion of operational performance by various researchers (see Table 2). Eco-packaging implies any changes made by product manufacturers or service providers to minimize the environmental impacts of packaging in the processes, products or services to consumers (Chuang, 2014). Packaging material can often cause a massive amount of waste because it becomes useless after the product is purchased. Therefore, during the operational processes, the use of recyclable (or biodegradable, recycled, renewable) materials, non-toxic and hazardless packaging materials, or refillable (or reusable) environmentally friendly packaging is important in order to reduce the waste caused by packaging (Zhu et al. 2007; Chuang, 2014).

### *3.5.Green Design*

Green design refers to the decrease in consumption and use of energy and materials, enabling the recovery, recycling and reuse of products, while minimizing any toxic materials to be used (Scur and Barbosa, 2017; dos Santos et al., 2019). It aims to reduce any environmental impact along the whole life of production starting from the raw material phase to the disposal of waste (Sellitto et al. 2019). Green design success lies in improving two cooperation dimensions - internal cooperation within the firm and external cooperation among the parties involved in the entire supply chain (Zhu and Sarkis 2006; Jabbour et al., 2015). Various researchers (see Table 2) have used green/eco design in terms of operational performance.

Table 2 shows the related literature concerning the criteria and measurements used to assess operational performance of GSCM.

**[Table 2 Near Here]**

## 4. Methodology

In this paper, a fuzzy Analytic Network Process (ANP) was used to find the respective weights of the criteria and the measurements, respectively. Then, a weighted scoring method was applied in order to find the total operational performance of the company. The reason for using fuzzy logic is its ability to overcome the subjectivity and vagueness of human judgement when dealing with uncertainties in the decision-making process. The advantage of using Fuzzy ANP is its ability to calculate the weights of the respective criteria within a network; a Weighted Scoring Method is implemented due to its ease of use and ability to calculate the weighted total score.

### *4.1. Fuzzy Analytic Network Process*

The ANP proposed by Saaty (1996) is one of the most popular MCDM techniques. It is one of the best methods with respect to handling qualitative and quantitative criteria easily (Chung et al, 2005). However, it has limited applicability in an uncertain and vague decision-making process (Onut et al., 2009). Zadeh (1965) proposed fuzzy set theory in order to reveal the usage of linguistic terms to overcome the subjective and vague judgments of people.

Regarding fuzzy membership functions, in this paper, triangular fuzzy numbers were used; this is indicated as ($l_{ij}$, $m_{ij}$, $r_{ij}$) referring to the smallest possible, the most likely and the largest possible values respectively (Kahraman et al., 2003).

Fuzzy extension of ANP differs from Saaty's (1996) approach because it incorporates fuzzy set theory (Onut et al., 2009). Fuzzy numbers are used to build pairwise comparison matrices. Although Saaty's (1980) scale of 1 to 9 has advantages, including simplicity and ease of use, the usage of linguistic terms to overcome the subjectivity and vagueness of human judgment is the better option.

Firstly, pairwise comparisons and priority vectors have been determined; then the initial supermatrix, weighted supermatrix and finally, limit supermatrix have been drawn up to calculate the weights of criteria respectively. See Sagnak and Kazancoglu (2019) for details.

### *4.2. Weighted Scoring Method*

In decision theory, a weighted scoring method is used for prioritization; it has been used in many studies in a wide range of applications. Abdolhamidzadeh et al. (2018) used a weighted scoring method for industrial emergency operations; Wang et al. (2018) used the method for genetic variations while Kannan et al. (2019) preferred it for software package selection. In order to find the total operational performance of the company, the individual performance scores of the measurements were multiplied with the respective measurement weights established from fuzzy ANP. The overall performance assessment score of operational activities was calculated by a weighted scoring method:

$$S_i = \sum_{j=1}^{n} S_{ij} w_j$$

where $S_i$ denotes the overall operational performance score, $S_{ij}$ represents the respective individual performance score of measurement $j$, and $w_j$ denotes the corresponding weight of measurement $j$.

## 5. Case Study

The application was conducted with a hot dip galvanizing company located in Izmir, Turkey. The firm's hot dip galvanizing production process includes the activities of degreasing, acid pickling, rinsing, fluxing, drying and dipping. With the consent of the Board of Directors, pairwise comparisons were made with fourteen authorities including the operations manager, the vice operations manager, the supply chain manager, the vice supply chain manager, the sustainability manager, the vice sustainability manager, a member of the executive board, the craft supervisor plus those blue-collar workers who are responsible for sustainable operations activities within the company. These authorities have been recognized as experts because of their experience in the field. For Fuzzy ANP matrices, each expert made the pairwise comparisons using the linguistic variables shown in Table 3.

**[Table 3 Near Here]**

The individual performance scores are determined using the linguistic scale seen in Table 4.

**[Table 4 Near Here]**

Table 5 shows the weights of the criteria, the weights of the measurements, individual (relative) weights of the measurements (found by multiplying the weights of respective criteria with respective measurements), individual performance scores for each measurement and overall performance score.

**[Table 5 Near Here]**

Here, the weights of criteria column represent the weights of five main criteria. The weights of measurements column correspond to the respective measurement weights in each cluster. The individual weights column specifies the measurement weights in the overall scale; in other words, we have taken into consideration the relative measurement weights in an overall manner. "Green Production/Manufacturing" was found as the most important criterion followed by "Quality Management" and "Efficiency Management" with weights of 0.322, 0.301 and 0.170 respectively.

Overall, "Yield Rate of Product" was found to be the most important measurement for evaluating the operational performance followed by "Operating Expense" with weights of 0.067 and 0.065 respectively.

The overall performance score for operational activities was 0.760; this is the operational excellence score based on the framework proposed in this study for the company to achieve GSCM.

## 6. Implications of this research

When the results of the study have been analyzed, several criteria reveal where the managers should generate necessary actions. These criteria are Quality Management, Green Production/Manufacturing and Green Design. Managerial implications will be proposed for each one of these three criteria.

The Quality Management factor has three performance scores that need to be improved. The relatively weak scores belong to Environmental Quality Management with an individual score of 0.546, Poka-Yoke Equipment with an individual score of 0.204 and Continuous Improvement System with an individual score of 0.653; hence, Lean-Green Approach will be suggested for this stage.

- **Lean-Green Approach**

The lean-green approach should be implemented by the managers to establish a sustainable supply chain for both inbound and outbound logistics by assuring zero waste and positive environmental impact. In that sense, the eight losses of lean management can be translated to green and sustainable principles. If overproduction can be reduced, a reduction in greenhouse gas emissions will be seen. In the galvanizing facility, with regard to energy use, any overproduction will result in an excess amount of energy use. The transportation arrangements can be minimized to reduce pollution and energy use. Practically, the problems about transportation can be solved in two ways. Firstly, vehicle routing models can be used when empty trucks are sent to collect metal products to be galvanized from various customers. Secondly, the transportation within the facility can be reduced by automated handling equipment. The people potential can be utilized by improving health and safety conditions; this will reduce occupational health diseases and staff absence. The workforce should be equipped with the necessary safety materials. Staff training programs can be conducted to prevent potential accidents from the fumes and splash of molten zinc. Unnecessary storage of materials should be minimized to reduce resource management and excessive water usage. This corresponds to the acid and rinsing phase in which the environmental impact of acid and excess use of water can be reduced. Decreasing the extra processes will decrease excessive power usage. The metal products should be cooled in order to get them dry before immersion into the molten zinc. Unnecessary motion causes inefficient resource usage; this is especially important where the use of cranes and other material handling equipment have a crucial role. Reducing waiting times will minimize the amount of rubbish generated. The minimization of defects will decrease the rework and scrap which in turn will decrease energy and resource use respectively. These implications will contribute to the sustainability of operations. In addition, these improvements will support the competiveness of the company via operational excellence and green supply chain management.

The Green Production/Manufacturing criterion has three performance scores that need to be improved. These relatively weak scores belong to Monitoring and Maintenance System with an individual score of 0.577, Minimizing Health & Safety Risks with an individual score of 0.686 and Minimizing Pollution related to Noise with an individual score of 0.593; hence, FMEA and OHSAS are proposed for Green Production/Manufacturing.

- **Failure Mode and Effect Analysis (FMEA) for Green Production**

Reliability management should be used in a preventive approach. Failure Mode and Effect Analysis (FMEA) can be the instrument used in order to study and analyze cases before they are operational, in terms of their occurrence, detectability and severity. Therefore, necessary actions can be taken accordingly. These scenarios may also involve environmental impacts as well as economic and social aspects; hence, the precautions or remedies may be designed by embracing the three pillars of Triple Bottom Line. In this business, the failure modes should be regarded as Kettle failure, Generator failure, Furnace failure, Crane failure, Dryer failure, Tank failure and Operator failure; these failure modes will be analyzed both individually and simultaneously with the aid of FMEA. In addition, various stochastic models can be implemented for reliability management and for FMEA in different processes of the company.

- **OHSAS for Health & Safety**

Occupational health and safety is a crucial topic, especially in the hot dip galvanizing sector, where both inherent processes and equipment may be the source of risks. Some of the significant risks can be listed as the splash of molten zinc particles during the immersion of materials in the molten zinc, risks related to cranes in terms of possible falls of improperly stabilized material, risks related to splash of acid from acid tanks plus the potential risk of high voltage electricity. Therefore, these risks require a systematic approach in their handling. OHSAS can be a starting point to cope with occupational health and safety issues and to contribute to social sustainability.

Green Design criterion has two performance scores that need to be improved. These relatively weak scores belong to Considering Remanufacturing within Design with an individual score of 0.686 and Concurrent Engineering with an individual score of 0.609. Matrix Organization Structure is proposed to institutionalize the Green Design.

- **Matrix Organization Structure for Organizational Structure**

Similar to quality and lean concepts, the design task is dependent on the experience and competence of various departments within the company. In addition to classical design task, green design needs additional capabilities and competencies related to the management activity of green supply chains. Within the circular view, design for remanufacturing shows promise for this sector. The current products are designed within the linear design perspective and are based on the existing manufacturing processes. Specific to the sector involved in the study, the need and number of welding and assembly processes could be analyzed and revised according to remanufacturing and recycling requirements in a circular manner. Hence, the green/eco design task should be seen as an inter-disciplinary task. It should be assigned to a team composed of representatives from different departments. In this way, concurrent engineering can be used to embrace these associated needs. The company must have a matrix organizational structure to carry out these inter-disciplinary tasks. By studying quality, lean processes and green design those drawbacks that are inherent in a hierarchical organizational structure can be avoided. Hence, the agility and flexibility of the company can be improved. These are important factors to maintain the competiveness of the company.

## 7. Conclusion

Nowadays, organizations are forced to pay attention to environmental considerations in conjunction with social and economic concerns. Businesses have started to become greener in their supply chain activities to decrease or eliminate waste and to protect natural resources. The term, green supply chain management (GSCM), has evolved as a concept to include green processes in supply chain activities; i.e. design, logistics, purchasing, packaging, manufacturing, marketing and reverse logistics.

The assessment of GSCM performance requires a holistic view of the entire supply chain. GSCM performance can be appraised by inclusion of both quantitative and qualitative factors.

Since one of the critical issues regarding GSCM practices is the operations, becoming green in the operational side of activities is important.

In this paper, a framework is proposed to evaluate the operational performance of a hot dip galvanizing company. The framework includes five criteria, namely Quality Management, Efficiency Management, Green Production / Manufacturing, Eco-Packaging, and Green Design. Firstly, the weights of the criteria and the respective measurements were found by Fuzzy ANP; then the overall operational performance score was found by the Weighted Scoring Method. The performance scores regarding each criterion were multiplied with the respective criterion weights to get an overall operational performance of the organization.

"Green Production/Manufacturing" was found to be the most important criterion followed by "Quality Management" and "Efficiency Management" with weights of 0.322, 0.301 and 0.170, respectively. Overall, "Yield Rate of Product" was found to be the most important measurement for evaluating the operational performance followed by "Operating Expense" with weights of 0.067 and 0.065, respectively. The overall performance score for operational activities was found to be 0.760, which means the company is operating at 76% efficiency.

This work has some limitations, such as the involvement of human beings in decision-making. This can be subjective and cannot be classified as definitive. Thus, the only limitation deemed to be valid for the study is the acquisition of data as a result of subjective evaluations.

This work conducts a case study in a manufacturing company in the Turkish context. Any future research may include the evaluation of green operational performance with modified criteria in different sectors with a modified framework in different nations The listed criteria may also be tested empirically in future. Further, the operational excellence of GSCM may also be evaluated in a circular economy environment.

## References

Abdolhamidzadeh B., Rahimi F., Gharebaghian T., Nosraty B., & Rashtchian D. (2018). Evaluating the Functionality of Industrial Emergency Operations Center (EOC) by Weighted Scoring Technique. In: Siddiqui N., Tauseef S., Abbasi S., Rangwala A. (eds) Advances in Fire and Process Safety. Springer Transactions in Civil and Environmental Engineering. Springer, Singapore.

Agarwal, A., Giraud-Carrier, F.C., & Li, Y. (2018). A mediation model of green supply chain management adoption: The role of internal impetus. International Journal of Production Economics, 205, 342-358.

Ageron, B., Gunasekaran, A., & Spalanzani, A. (2012). Sustainable supply management: An empirical study. International Journal of Production Economics, 140(1), 168-182.

Ahi, P., & Searcy, C. (2015). An analysis of metrics used to measure performance in green and sustainable supply chains. Journal of Cleaner Production, 86, 360-377.

Alvarez-Rodriguez, C., Martin-Gamboa, M., & Iribarren, D. (2019). Combined use of Data Envelopment Analysis and Life Cycle Assessment for operational and environmental benchmarking in the service sector: A case study of grocery stores. Science of the Total Environment, 667, 799-808.

Aydiner, A.S., Tatoglu, E., Bayraktar, E., Zaim, S., & Delen, D. (2019). Business analytics and firm performance: The mediating role of business process performance. Journal of Business Research, 96, 228-237.

Azevedo, S.G., Carvalho, H., & Machado, C. (2011). The influence of green practices on supply chain performance: a case study approach. Transportation Research Part E: Logistics and Transportation Review, 47(6), 850-871.

Beamon, B.M. (1999). Measuring supply chain performance. International Journal of Operations & Production Management, 19(3), 275-292.

Bhattacharya, A., Mohapatra, P., Kumar, V., Dey, P.K., Brady, M., Tiwari, M.K., & Nudurupati, S.S. (2014). Green supply chain performance measurement using fuzzy ANP-based balanced scorecard: a collaborative decision-making approach. Production Planning & Control, 25(8), 698-714.

Chand, M., Bhatia, N., & Singh, R.K. (2018). ANP-MOORA-based approach for the analysis of selected issues of green supply chain management. Benchmarking: An International Journal, 25(2), 642-659.

Chaudhary, T., & Chanda, A.K. (2015). Evaluation and measurement of performance, practice and pressure of green supply chain in Indian manufacturing industries. Uncertain Supply Chain Management, 3, 363-374.

Chavez, R., Yu, W., Feng, M., & Wiengarten, F. (2016). The effect of customer-centric Green supply chain management on operational performance and customer satisfaction. Business Strategy and the Environment, 25(3), 205-220.

Cherrafi, A., Garza-Reyes, J.A., Kumar, V., Mishra, N., Ghobadian, A., & Elfezazi, S. (2018). Lean, green practices and process innovation: A model for green supply chain performance. International Journal of Production Economics, 206, 79-92

Chia, A., Goh, M., & Hum, S.H. (2009). Performance measurement in supply chain entities: balanced scorecard perspective. Benchmarking: An International Journal, 16(5), 605-620.

Christiansen, T., Berry, W.L., Bruun, P., & Ward, P. (2003). A mapping of competitive priorities, manufacturing practices, and operational performance in groups of Danish manufacturing companies. International Journal of Operations & Production Management, 23(10), 1163-1183.

Chuang, S.P. (2014). Assessing and improving the green performance using a compound approach. Flexible Services and Manufacturing Journal, 26(1-2), 69-91.

Chung, S.H., Lee, A.H., & Pearn, W.L. (2005). Product mix optimization for semiconductor manufacturing based on AHP and ANP analysis. International Journal of Advanced Manufacturing Technology, 25(11-12), 1144-1156.

Damanpour, F., & Wischnevsky, J.D. (2006). Research on innovation in organizations: Distinguishing innovation-generating from innovation-adopting organizations. Journal of Engineering and Technology Management, 23(4), 269-291.

Dawei, Z., Hamid, A.B.A., Chin, T.A., & Leng, K.C. (2015). Green Supply Chain Management: A Literature Review. Sains Humanika, 5(2), 15-21.

de Oliveira, U.R., Espindola, L.S., da Silva, I.R., da Silva, I.N., & Rocha, H.M. (2018). A systematic literature review on green supply chain management: research implications and future perspectives. Journal of Cleaner Production, 187, 537-561.

Diab, S.M., AL-Bourini, F.A., & Abu-Rumman, A.H. (2015). The impact of green supply chain management practices on organizational performance: a study of Jordanian food industries. Journal of Management and Sustainability, 5(1), 149-157.

Diabat, A., & Govindan, K. (2011). An analysis of the drivers affecting the implementation of green supply chain management. Resources, Conservation & Recycling, 55(6), 659-667.

Diabat, A., Khodaverdi, R., & Olfat, L. (2013). An exploration of green supply chain practices and performances in an automotive industry. International Journal of Advanced Manufacturing Technology, 68(1-4), 949-961.

dos Santos, B.M., Godoy, L.P., & Campos, L.M.S. (2019). Performance evaluation of green suppliers using entropy-TOPSIS-F. Journal of Cleaner Production, 207, 498-509.

Duarte, S., Cabrita, R., & Machado, V.C. (2011). Exploring lean and green supply chain performance using balanced scorecard perspective. Paper presented at the 2011 International Conference on Industrial Engineering and Operations Management, Kuala Lumpur, Malaysia, January 22-24.

Dubey, R., Gunasekaran, A., & Ali, S.S. (2015). Exploring the relationship between leadership, operational practices, institutional pressures and environmental performance: a framework for green supply chain. International Journal of Production Economics, 160, 120-132.

Dubey, R., Gunasekaran, A., & Papadopoulos, T. (2017). Green supply chain management: theoretical framework and further research directions. Benchmarking: An International Journal, 24(1), 184-218.

Farias, L.M.S., Santos, L.C., Gohr, C.F., & Rocha, L.O. (2019a). An ANP-based approach for lean and green performance assessment. Resources, Conservation & Recycling, 143, 77-89.

Farias, L.M.S., Santos, L.C., Gohr, C.F., de Oliveira, L.C., & da Silva Amorim, M.H. (2019b). Criteria and practices for lean and green performance assessment: Systematic review and conceptual framework. Journal of Cleaner Production, 218, 746-762.

Frohlich, M.T., & Westbrook, R. (2001). Arcs of integration: an international study of supply chain strategies. Journal of Operations Management, 19(2), 185-200.

Gardas, B.B., Raut, R.D., & Narkhede, B. (2019). Determinants of sustainable supply chain management: A case study from the oil and gas supply chain. Sustainable Production and Consumption, 17, 241-253.

Gavronski, I., Klassen, R.D., Vachon, S., & Nascimento, L.F.M.D. (2011). A resource-based view of green supply management. Transportation Research Part E: Logistics and Transportation Review, 47(6), 872-885.

Geng, R., Mansouri, S.A., & Aktas, E. (2017). The relationship between green supply chain management and performance: a meta-analysis of empirical evidences in Asian emerging economies. International Journal of Production Economics, 183, 245-258.

Giovanni, P.D., & Vinzi, V.E. (2012). Covariance versus component-based estimations of performance in green supply chain management. International Journal of Production Economics, 135(2), 907-916.

Gokarn, S., & Kuthambalayan, T.S. (2019). Creating sustainable fresh produce supply chains by managing uncertainties. Journal of Cleaner Production, 207, 908-919.

Gólcher-Barguil, L.A., Nadeem, S.P., & Garza-Reyes, J.A. (2019). Measuring operational excellence: an operational excellence profitability (OEP) approach. Production Planning & Control, 30(8), 682-698.

Gonzalez P., Sarkis J., & Diaz, A. (2008). Environmental management system certification and its influence on corporate practices Evidence from the automotive industry. International Journal of Operations & Production Management, 28(11), 1021-1041.

Govindan, K., & Popiuc, M.N. (2014). Reverse supply chain coordination by revenue sharing contract: a case for the personal computers industry. European Journal of Operational Research, 233(2), 326-336.

Govindan, K., Khodaverdi, R., & Vafadarnikjoo, A. (2015a). Intuitionistic fuzzy based DEMATEL method for developing green practices and performances in a green supply chain. Expert Systems with Applications, 42(20), 7207-7220.

Govindan, K., Soleimani, H., & Kannan, D. (2015b). Reverse logistics and closed-loop supply chain: a comprehensive review to explore the future. European Journal of Operational Research, 240, 603-626.

Govindan, K., Muduli, K., Devika, K., & Barve, A. (2016). Investigation of the influential strength of factors on adoption of green supply chain management practices: An Indian mining scenario. Resources, Conservation & Recycling, 107, 185-194.

Green Jr., K.W., Whitten, D., & Inman, R.A. (2008). The impact of logistics performance on organizational performance in a supply chain context. Supply Chain Management: An International Journal, 13(4), 317-327.

Gunasekaran, A., & Kobu, B. (2007). Performance measures and metrics in logistics and supply chain management: A review of recent literature (1995–2004) for research and applications. International Journal of Production Research, 45(12), 2819-2840.

Hanna, M.D., Newman, W.R., & Johnson, P. (2000). Linking operational and environmental improvement through employee involvement. International Journal of Operations & Production Management, 20(2), 148-165.

Henao, R., Sarache, W., & Gomez, I. (2019). Lean manufacturing and sustainable performance: Trends and future challenges. Journal of Cleaner Production, 208, 99-116.

Hervani, A.A., Helms, M.M., & Sarkis, J. (2005). Performance measurement for green supply chain management. Benchmarking: An International Journal, 12(4), 330-353.

Holt, D., & Ghobadian, A. (2009). An empirical study of green supply chain management practices amongst UK manufacturers. Journal of Manufacturing Technology Management, 20(7), 933-956.

Hsu, C.-C., Kannan, V.R., Tan, K.-C., & Keong Leong, G. (2008). Information sharing, buyer-supplier relationships, and firm performance: A multi-region analysis. International Journal of Physical Distribution & Logistics Management, 38(4), 296–310.

Hsu, C.-W., Kuo, T.-C., Chen, S.-H., & Hu, A.H. (2013). Using DEMATEL to develop a carbon management model of supplier selection in green supply chain management. Journal of Cleaner Production, 56, 164-172.

Hu, A.H., & Hsu, C.W. (2006). Empirical study in the critical factors of green supply chain management (GSCM) practice in the Taiwanese electrical and electronics industries. In 2006 IEEE International Conference on Management of Innovation and Technology, 853-857.

Hubbard, G. (2009). Measuring organizational performance: beyond the triple bottom line. Business Strategy and the Environment, 18(3), 177-191

Hugo, A., & Pistikopoulos, E. (2005). Environmentally conscious long-range planning and design of supply chain networks. Journal of Cleaner Production, 13(15), 1471-1491.

Humphreys, P.K., McIvor, R., & Chan, F.T.S. (2003). Using case-based reasoning to evaluate supplier environmental management performance. Expert Systems with Applications, 25(2), 141-153.

Huo, B., Zhao, X., & Zhou, H. (2014). The effects of competitive environment on supply chain information sharing and performance: An empirical study in China. Production and Operations Management, 23(4), 552-569.

Jabbour, C.J.C., Jabbour, A.B.L., Govindan, K., Teixeira, A.A., & Freitas, W.R. (2013). Environmental management and operational performance in automotive companies in Brazil: the role of human resource management and lean manufacturing. Journal of Cleaner Production, 47, 129-140.

Jabbour, A.B.L., Junior, J.C.O, & Jabbour, C.J.C. (2014). Extending lean manufacturing in supply chains: a successful case in Brazil. Benchmarking: An International Journal, 21(6), 1070-1083.

Jabbour, A.B.L., de Oliveira Frascareli, F.C., & Jabbour, C.J.C. (2015). Green supply chain management and firms' performance: understanding potential relationships and the role of green sourcing and some other green practices. Resources, Conservation & Recycling, 104, 366-374.

Jabbour, C.J.C., & Jabbour, A.B.L. (2016). Green human resource management and green supply chain management: linking two emerging agendas. Journal of Cleaner Production, 112, 1824-1833.

Kahraman, C., Ruan, D., & Dogan, I. (2003). Fuzzy group decision making for facility location selection. Information Sciences, 157, 135-153.

Kannan, A.S.K., Balamurugan, S.A., & Sasikala, S. (2019). A Novel Software Package Selection Method Using Teaching-Learning Based Optimization and Multiple Criteria Decision Making. IEEE Transactions on Engineering Management, in print. https://doi.org/10.1109/TEM.2019.2918050

Kazancoglu, Y., Kazancoglu, I., & Sagnak, M. (2018). A new holistic conceptual framework for green supply chain management performance assessment based on circular economy. Journal of Cleaner Production, 195, 1282-1299.

Klein, R., & Rai, A. (2009). Interfirm strategic information flows in logistics supply chain relationships. MIS Quarterly, 33(4), 735-762.

Koberg, E., & Longoni, A. (2019). A systematic review of sustainable supply chain management in global supply chains, Journal of Cleaner Production, 207, 1084-1098.

Lai, Y.L., Hsu, M.S., Lin, F.J., Chen, Y.M., & Lin, Y.H. (2014). The effects of industry cluster knowledge management on innovation performance. Journal of Business Research, 67(5), 734-739.

Lee, A.H., Kang, H.Y., Hsu, C.F., & Hung, H.C. (2009). A green supplier selection model for high-tech industry. Expert Systems with Applications, 36(4), 7917-7927.

Lewis, H., & Gertsakis, J. (2001). Design and Environment: a Global Guide to Designing Greener Goods. Greenleaf Publishing, Sheffield.

Lin, R.J. (2013). Using fuzzy DEMATEL to evaluate the green supply chain management practices. Journal of Cleaner Production, 40, 32-39.

Lin, Y., Tseng, M.L., Chiu, A.S.F., & Wang, R. (2014). Implementation and performance evaluation of a Firm's Green supply chain management under uncertainty. Industrial Engineering & Management Systems, 13(1), 15-28.

Lippmann, S. (1999). Supply chain environmental management: elements for success. Corporate Environmental Strategy, 6, 175-182.

Luthra, S., Garg, D., & Haleem, A. (2016). The impacts of critical success factors for implementing green supply chain management towards sustainability: an empirical investigation of Indian automobile industry. Journal of Cleaner Production, 121(1), 142-158.

Luthra, S., Mangla, S.K., & Yadav, G. (2019). An analysis of causal relationships among challenges impeding redistributed manufacturing in emerging economies. Journal of Cleaner Production, 225, 949-962.

Malviya, R.K., & Kant, R. (2015). Green supply chain management (GSCM): a structured literature review and research implications. Benchmarking: An International Journal, 22(7), 1360-1394.

Min, H., & Kim, I. (2012). Green supply chain research: past, present, and future. Logistics Research, 4(1), 39-47.

Mumtaz, U., Ali, Y., & Petrillo, A. (2018). A linear regression approach to evaluate the green supply chain management impact on industrial organizational performance. Science of the Total Environment, 624, 162-169.

Nguene, G., Fragnière, E., Kanala, R., Lavigne, D., & Moresino, F. (2011). SOCIO-MARKAL: integrating energy consumption behavioral changes in the technological optimization framework. Energy for Sustainable Development, 15(1), 73–83.

Noh, J., & Kim, J.S. (2019). Cooperative green supply chain management with greenhouse gas emissions and fuzzy demand. Journal of Cleaner Production, 208, 1421-1435.

Okoshi, C.Y., de Lima, E.P., & Da Costa, S.E.G. (2019). Performance cause and effect studies: Analyzing high performance manufacturing companies. International Journal of Production Economics, 210, 27-41.

Onut, S., Kara, S.S., & Isik, E. (2009). Long term supplier selection using a combined fuzzy MCDM approach: A case study for a telecommunication company. Expert Systems with Applications, 36, 3887-3895.

Pauli, G. (1997). Zero emissions: the ultimate goal of cleaner production. Journal of Cleaner Production, 5(1), 109-113.

Paulraj, A. (2009). Environmental motivations: a classification scheme and its impact on environmental strategies and practices. Business Strategy and the Environment, 18(7), 453-468.

Pereira-Moliner, J., Claver-Cortés, E., Molina-Azorín, J.F., & José Tarí, J. (2012). Quality management, environmental management and firm performance: direct and mediating effects in the hotel industry. Journal of Cleaner Production, 37, 82-92.

Pourjavad, E., & Shahin, A. (2018). The application of mamdani fuzzy inference system in evaluating Green supply chain management performance. International Journal of Fuzzy Systems, 20(3), 901-912.

Prajogo, D., Chowdhury, M., Yeung, A.C., & Cheng, T.C.E. (2012). The relationship between supplier management and firm's operational performance: a multi-dimensional perspective. International Journal of Production Economics, 136(1), 123-130.

Rao, P., & Holt, D. (2005). Do green supply chains lead to competitiveness and economic performance? International Journal of Operations & Production Management, 25(9), 898-916.

Ray, C.D., Zuo, X., Michael, J.H., & Wiedenbeck, J.K. (2006). The Lean Index: Operational "Lean" Metrics for The Wood Products Industry. Wood and Fiber Science, 38, 238-255.

Rivera, J. (2019). An integral model for the implementation of environmental policy strategy. Business Strategy and the Environment, 28(5), 909-920.

Rostamzadeh, R., Govindan, K., Esmaeili, A., & Sabaghi, M. (2015). Application of fuzzy VIKOR for evaluation of green supply chain management practices. Ecological Indicators, 49, 188-203.

Saaty, T.L. (1980). The Analytic Hierarchy Process. McGraw-Hill, New York.

Saaty, T.L. (1996). Decision Making with Dependence and Feedback: The Analytic Network Process. RWS Publications, Pittsburgh.

Saaty, T.L., & Vargas, L.G. (1998). Diagnosis with dependent symptoms: Bayes theorem and the analytic hierarchy process. Operations Research, 46(4), 491-502.

Sagnak, M., & Kazancoglu, Y. (2019). Integrated Fuzzy Analytic Network Process and 0-1 Goal Programming Technique for Enterprise Resource Planning (ERP) Software Selection. Ege Academic Review, 19(1), 75-88.

Sarkis, J. (1998). Evaluating environmentally conscious business practices. European Journal of Operational Research, 107(1), 159-174.

Sarkis, J. (2001). Greener Manufacturing and Operations: from Design to Delivery and Back. Greenleaf Publishing.

Scur, G., & Barbosa, M.E. (2017). Green supply chain management practices: multiple case studies in the Brazilian home appliance industry. Journal of Cleaner Production, 141, 1293-1302.

Sehnem, S., Jabbour, C.J.C., Pereira, S.C.F., & de Sousa Jabbour, A.B.L. (2019). Improving sustainable supply chains performance through operational excellence: circular economy approach. Resources, Conservation & Recycling, 149, 236-248.

Sellitto, M.A., Hermann, F.F., Blezs Jr., A.E., & Barbosa-Póvoa, A.P. (2019). Describing and organizing green practices in the context of Green Supply Chain Management: Case studies. Resources, Conservation & Recycling, 145, 1-10.

Shang, K.C., Lu, C.S., & Li, S. (2010). A taxonomy of green supply chain management capability among electronics-related manufacturing firms in Taiwan. Journal of Environmental Management, 91(5), 1218-1226.

Sidiropoulos, M., Mouzakitis, Y., Adamides, & E., Goutsos, S. (2004). Applying sustainable indicators to corporate strategy: the eco-balanced scorecard. Environmental Research, Engineering and Management, 1(27), 28-33.

Sikdar, S.K., & Howell, S.G. (1998). On developing cleaner organic unit processes. Journal of Cleaner Production, 6(3), 253-259.

Srivastava, S. (2007). Green supply-chain management: a state-of-the-art literature review. International Journal of Management Reviews, 9(1), 53-80.

Tseng, M.-L., Islam, M.S., Kariab, N., Fauzib, F.A. & Afrin, S. (2019). A literature review on green supply chain management: Trends and future challenges, Resources, Conservation & Recycling, 141, 145-162.

Tseng, M.-L., Lin, Y.H., Tan, K., Chen, R.H., & Chen, Y.H. (2014). Using TODIM to evaluate green supply chain practices under uncertainty. Applied Mathematical Modelling, 38, 2983-2995.

Tyagi, M., Kumar, P., & Kumar, D. (2015). Parametric selection of alternatives to improve performance of green supply chain management system. Procedia - Social and Behavioral Sciences, 189, 449-457.

Uygun, O., & Dede, A. (2016). Performance evaluation of green supply chain management using integrated fuzzy multi-criteria decision-making techniques. Computers & Industrial Engineering, 102, 502-511.

Vachon, S., & Klassen, R.D. (2007). Supply chain management and environmental technologies: the role of integration. International Journal of Production Research, 45(2), 401-423.

Vachon, S., & Klassen, R.D. (2008). Environmental management and manufacturing performance: the role of collaboration in the supply chain. International Journal of Production Economics, 111(2), 299-315.

van Hoof, B., & Lyon, T.P. (2013). Cleaner production in small firms taking part in Mexico's Sustainable Supplier Program. Journal of Cleaner Production, 41, 270-282.

Wang, J., Ullah, A.Z.D., & Chelala, C. (2018). IW-Scoring: an Integrative Weighted Scoring framework for annotating and prioritizing genetic variations in the noncoding genome. Nucleic Acids Research, 46(8), 47-60.

Wee, H.M., Lee, M.C., Jonas, C.P., & Wang, C.E. (2011). Optimal replenishment policy for a deteriorating green product: life cycle costing analysis. International Journal of Production Economics, 133(2), 603-611.

Wu, K-J., Tseng, M-L., & Vy, T. (2011). Evaluation the drivers of green supply chain management practices in uncertainty. Procedia - Social and Behavioral Sciences, 25, 384-397.

Wu, K.J., Liao, C.J., Tseng, M.L., & Chiu, A.S. (2015). Exploring decisive factors in green supply chain practices under uncertainty. International Journal of Production Economics, 159, 147-157.

Xie, X., Zhu, Q., & Wang, R. (2019). Turning green subsidies into sustainability: How green process innovation improves firms' green image. Business Strategy and the Environment, 28(7), 1416-1433.

Yadav, G., & Desai, T.N. (2016). Lean Six Sigma: a categorized review of the literature. International Journal of Lean Six Sigma, 7(1), 2-24.

Yadav, G., Seth, D., & Desai, T.N. (2018). Prioritising solutions for Lean Six Sigma adoption barriers through fuzzy AHP-modified TOPSIS framework. International Journal of Lean Six Sigma, 9(3), 270-300.

Younis, H., Sundarakani, B., & Vel, P. (2016). The impact of implementing green supply chain management practices on corporate performance. Competitiveness Review, 26(3), 216-245.

Yu, W., Chavez, R., & Feng, M. (2017). Green supply management and performance: a resource-based view. Production Planning & Control, 28(6-8), 659-670.

Yu, W., Chavez, R., Feng, M., & Wiengarten, F. (2014). Integrated green supply chain management and operational performance. Supply Chain Management: An International Journal, 19(5/6), 683-696.

Zadeh, L.A. (1965). Fuzzy sets. Information Control, 8, 338-353.

Zhang, F., Rio, M., Allais, R., Zwo Linski, P., Carrillo, T.R., Roucoules, L., Mercier-Laurent, E., & Buclet, N. (2013). Toward a systematic navigation framework to integrate sustainable development into the company. Journal of Cleaner Production, 54(1), 199-214.

Zhang, H., & Yang, F. (2016). On the drivers and performance outcomes of green practices adoption: an empirical study in China. Industrial Management & Data Systems, 116(9), 2011-2034.

Zhu, Q., Geng, Y., & Lai, K.H. (2010). Circular economy practices among Chinese manufacturers varying in environmental-oriented supply chain cooperation and the performance implications. Journal of Environmental Management, 91(6), 1324-1331.

Zhu, Q., & Sarkis, J. (2006). An inter-sectoral comparison of green supply chain management in China: drivers and practices. Journal of Cleaner Production, 14(5), 472-486.

Zhu, Q., Sarkis, J., & Geng, Y. (2005). Green supply chain management in China: pressures, practices and performance. International Journal of Operations & Production Management, 25(5), 449-468.

Zhu, Q., Sarkis, J., & Lai, K.H. (2007). Green supply chain management: pressures, practices and performance within the Chinese automobile industry. Journal of Cleaner Production, 15, 1041-1052.

Zhu, Q., Sarkis J., & Lai, K.H. (2008). Confirmation of a measurement model for green supply chain management practices implementation. International Journal of Production Economics, 111, 261-273.

Zhu, Q., Sarkis, J., & Lai, K.H. (2013). Institutional-based antecedents and performance outcomes of internal and external green supply chain management practices. Journal of Purchasing and Supply Management, 19(2), 106-117.

**Table 1: Proposed framework for operational performance of GSCM**

| Operational Performance | | | | |
|---|---|---|---|---|
| **Quality Management** | **Efficiency Management** | **Green Production/Manufacturing** | **Eco-Packaging** | **Green Design** |
| Customer Rejection Rate | Overhead Expense | Redefinition of Operational Processes | Minimizing Toxic and Hazardous Materials within Packaging | Minimizing the Consumption of Energy |
| Yield Rate of Product | Operating Expense | Minimizing the use of Toxic and Hazardous Raw Materials | Recyclable items in Packaging | Using Reused Materials within New Designs |
| Percentage of Defective Items | Capacity Utilization | Recyclable Raw Materials | Recycled items in Packaging | Using Recycled Materials within New Designs |
| Environmental Quality Management | Energy Consumption | Recycled Raw Materials | Cooperation with Customers for Eco-Packaging | Minimizing the use of resources and generation of waste |
| Satisfaction of Employees in Green Operations | | Waste and Pollution and Tracking Devices | Cooperation with Suppliers for Eco-Packaging | Minimizing Hazardous Materials and Processes |
| Poka-Yoke Equipment | | Structure for Easy Disassembly | Using Eco-Labels in Packaging Process | Less Volume for Storage |
| Continuous Improvement System | | Monitoring and Maintenance System | Labelling for Retrieval Purpose | Simplifying the installation and setup to save Energy |
| Scrap Rate | | Inventory Levels | | Extending Product/Service Life Duration |
| Rework Rate | | Reduction in Operation Steps | | Reducing Raw Material Consumption |
| | | Minimizing the Amount of Hazardous Processes within Manufacturing | | Considering Remanufacturing within Design |
| | | Minimizing the Quantity of Hazardous Equipment and Devices | | Concurrent Engineering |
| | | Minimizing Health & Safety Risks | | Collaboration with Customers on Green Design |
| | | Adapting Eco/Green Technology | | Collaboration with Suppliers on Green Design |
| | | Simplifying the Assembling Operations | | Patent Numbers on Green/Eco Products |
| | | Scheduling Production for Waste Reduction | | Life Cycle Costing |
| | | Designing Processes to be more energy efficient | | LCA-Life Cycle Assessment |
| | | Designing Processes to Minimize Waste | | |
| | | Minimizing Pollution Related to Noise | | |
| | | Using Renewable Energy based resources | | |
| | | Investment in Green/Eco Machinery and Technology | | |
| | | Collaboration with Customers on Green Production/Manufacturing | | |

**Table 2: Criteria and measurements to assess operational performance of GSCM**

| | Definition | Main References |
|---|---|---|
| **Quality Management** | | |
| Customer Rejection Rate | The percentage of complete units rejected or returned by external customers | Christiansen et al. (2003); Azevedo (2011) |
| Yield Rate of Product | The percentage of defect free units produced from the maximum possible mass. | Christiansen et al. (2003); Azevedo (2011) |
| Percentage of Defective Items | The percentage of defect units produced from the maximum possible mass. | Christiansen et al. (2003); Hugo and Pistikopoulos (2005); Hubbard (2009); Azevedo (2011); Duarte et al. (2011); Diabat et al. (2013) |
| Environmental Quality Management | Managerial activities that reduce or prevent environmental pollution achieved through TQM techniques. | Pauli (1997); Rao and Holt (2005); Zhu et al. (2005); Zhu and Sarkis (2006); Zhu et al. (2007); Zhu et al. (2008); Green et al. (2008); Gavronski et al. (2011); Prajogo et al. (2012); Pereira-Moliner et al. (2012); Diabat et al. (2013); Jabbour et al. (2014); Dubey et al. (2015) |
| Satisfaction of Employees in Green Operations | Learning and attaining innovation benefits from green processes improve employee morale and satisfaction. | Sidiropoulos et al. (2004); Ray et al. (2006); Hubbard (2009); Chia et al. (2009); Duarte et al. (2011); |
| Poka-Yoke Equipment | The mistake proofing procedure or device used to prevent a defect during the green processes | Chuang (2014) |
| Continuous Improvement System | Manufacturing operations processes continuous improvement systems, processes and procedures development. | Chuang (2014); Okoshi et al. (2019) |
| Scrap Rate | The proportion of parts produced that are defective | Zhu et al. (2005); Zhu et al. (2007); Duarte et al. (2011); Ageron et al. (2012); Zhu et al. (2013); Rostamzadeh et al. (2015); Cherrafi et al. (2018); Henao et al. (2019) |
| Rework Rate | The proportion of produced parts discovered to require change | Ageron et al. (2012); Cherrafi et al. (2018); Henao et al. (2019) |
| **Efficiency Management** | | |
| Overhead Expense | An ongoing expense of operating a business | Jiang et al. (2006); Azevedo (2011) |
| Operating Expense | Expenses related to the production of goods | Jiang et al. (2006); Azevedo (2011) |
| Capacity Utilization | It refers to how much of a factory's production capacity is currently being utilized | Zhu et al. (2005); Zhu et al. (2007); Zhu et al. (2008); Farias et al. (2019b) |
| Energy Consumption | Method of minimizing the consumption of energy by consuming less energy to attain same amount of useful output and to be energy efficient | Ahi and Searcy (2015); Farias et al. (2019b) |
| **Green Production/Manufacturing** | | |
| Redefinition of Operational Processes | Redefining operation and production processes for greening operations | Tseng et al. (2014). |
| Minimizing the use of Toxic and Hazardous Raw Materials | Reducing the use of toxic and hazardous raw materials during manufacturing | Chuang (2014) |

| | | |
|---|---|---|
| Recyclable Raw Materials | Using recyclable raw materials during the production | Chuang (2014) |
| Recycled Raw Materials | Using recycled raw materials during the production | Diabat et al. (2013); Chuang (2014) |
| Waste and Pollution and Tracking Devices | Using devices to reduce waste and monitor pollution | Chia et al. (2009); Duarte et al. (2011); Chuang (2014); Bhattacharya, et al. (2014); Farias et al. (2019b) |
| Structure for Easy Disassembly | The structure of materials is designed for easy disassembly and reuse | Chuang (2014) |
| Monitoring and Maintenance System | It refers to all the indicators, tools and processes that provide resilience, reliability, and maximized up-time. | Chuang (2014) |
| Inventory Levels | Items kept in stock to process or resell. | Zhu et al. (2005); Ray et al. (2006); Zhu et al. (2007); Zhu et al. (2008); Green et al. (2008); Duarte et al. (2011); Diabat et al. (2013); Zhu et al. (2013); Bhattacharya, et al. (2014); Dubey et al. (2015); Farias et al. (2019a); Henao et al. (2019) |
| Reduction in Operation Steps | Minimization of the amount of manufacturing operational steps. | Chuang (2014); Dubey et al. (2015) |
| Minimizing the Amount of Hazardous Processes within Manufacturing | Minimization of the amount of hazardous substances and processes where stored, handled or used. | Zhu et al. (2007); Green et al. (2008); Zhu et al, (2008); Shang et al. (2010) |
| Minimizing the Quantity of Hazardous Equipment and Devices | Minimization of the amount of hazardous machinery and equipment | Zhu et al. (2007); Green et al. (2008); Zhu et al, (2008); Shang et al. (2010) |
| Minimizing Health & Safety Risks | Minimization of exposure to risks related to occupational health & safety | Diabat et al. (2013); Chuang (2014) |
| Adapting Eco/Green Technology | The adaptation of environmentally friendly technologies based on the necessities of production process or supply chain. | Sikdar and Howell (1998); Nguene et al. (2011); Zhang et al. (2013); van Hoof and Lyon (2013); Akman and Mishra (2015); Dubey, et al. (2015) |
| Simplifying the Assembling Operations | Supporting structure to assembly products easily. | Chuang (2014) |
| Scheduling Production for Waste Reduction | The production scheduling and control of operations with both inputs, the ingredients to a process, and outputs, the results of a process by taking waste reduction into consideration | Shang et al. (2010); Wu et al. (2011) |
| Designing Processes to be more energy efficient | Designing Production Processes in order to minimize energy consumption and resource use | Shang et al. (2010) |
| Designing Process to Minimize Waste | Process design focused on minimizing pollution and waste in production processes. | Zhu et al. (2010); Diabat et al. (2013); Zhu et.al (2013); Yadav et al. (2018) |
| Minimizing Pollution Related to Noise | Reducing the noise pollution to minimize its effects. | Shang et al. (2010) |
| Using Renewable Energy based resources | Maximizing renewable (energy) resources for manufacturing operations. | Chaudhary and Chanda (2015) |
| Investment in Green/Eco Machinery and Technology | Acquisition of clean devices and technologies | Shang et al. (2010); Tseng et al. (2014) |
| Collaboration with Customers on Green Production/Manufacturing | Green manufacturing through cooperation with customers | Zhu et al. (2007); Zhu et al. (2008); Diabat et al. (2013); Bhattacharya, et al. (2014) |
| **Eco-Packaging** | | |
| Minimizing Toxic and Hazardous Materials within Packaging | Non-toxic and hazardless packaging materials are used | Chuang (2014); Chaudhary and Chanda (2015) |

| | | |
|---|---|---|
| Recyclable items in Packaging | Recyclable materials are used in packaging | Chuang (2014) |
| Recycled items in Packaging | Recycled materials are used in packaging | Chuang (2014) |
| Cooperation with Customers for Eco-Packaging | Collecting ideas and suggestions of customers for eco packaging, information sharing for a better customer feedback system. | Zhu et al. (2008); Ahi and Searcy (2015); Gardas et al. (2019) |
| Cooperation with Suppliers for Eco-Packaging | Collecting ideas and suggestions from suppliers for green packaging, information sharing to improve suppliers' and vendors' performance. | Zhu et al. (2008); Ahi and Searcy (2015); Gardas et al. (2019) |
| Using Eco-Label in Packaging Process | Eco-labels on material package are used to reflect the life cycle impacts of a product to match with the environmental considerations of customers | Diabat (2013); Chuang (2014); Tseng et al. (2014); Rostamzadeh et al. (2015); Chaudhary and Chanda (2015) |
| Labelling for Retrieval Purpose | Material packages are labeled for storage and retrieval. | Shang et al. (2010) |
| **Green Design** | | |
| Minimizing the Consumption of Energy | Minimizing the use of energy by applying green design measures | Rao and Holt (2005); Gonzalez et al. (2008); Zhu et al. (2008); Paulraj (2009); Holt and Ghobadian (2009); Diabat et al. (2013); Chuang (2014); Rostamzadeh et al. (2015) |
| Using Reused Materials within New Designs | Using eco-friendly and reused materials during new product designs | Zhu (2008); Diabat et al. (2013); Rostamzadeh et al. (2015) |
| Using Recycled Materials within New Designs | Using eco-friendly and recycled materials during new product designs | Beamon (1999), Zhu (2008); Rostamzadeh et al. (2015) |
| Minimizing the use of resources and generation of waste | Designs focused on reducing waste and resource use through the product life cycle | Shang et al. (2010) |
| Minimizing Hazardous Materials and Processes | Designs focused on minimizing the usage and inclusion of hazardous materials and production processes | Shang et al. (2010) |
| Less Volume for Storage | Design the product to use less area to store | Chaudhary and Chanda (2015) |
| Simplifying the installation and setup to save Energy | Design the product for easy setup in most energy efficient way | Chaudhary and Chanda (2015) |
| Extending Product/Service Life Duration | Design service/product for a longer life cycle | Chuang (2014) |
| Reducing Raw Material Consumption | Designing product to reduce material use | Zhu, et al. (2005); Zhu et al. (2007); Zhu et al. (2013) |
| Considering Remanufacturing within Design | Designing the product by considering circular economy and taking refurbishment, rework and repair activities into account | Diabat et al. (2013); Luthra et al. (2019) |
| Concurrent Engineering | Practice of incorporating various values to design a product at early development stages | Giovanni and Vinzi (2012) |
| Collaboration with Customers on Green Design | Green design for service/product through collaboration with customers | Zhu, et al. (2005); Zhu et al. (2008); Diabat et al. (2013); Bhattacharya, et al. (2014); Rostamzadeh et al. (2015); Chaudhary and Chanda (2015) |
| Collaboration with Suppliers on Green Design | Green design for service/product through collaboration with suppliers | Lippmann (1999); Zhu, et al. (2005); Hu and Hsu (2006); Zhu and Sarkis (2006); Zhu et al. (2007); Vachon, Klassen (2007); Zhu et al. (2008); Vachon and Klassen (2008); Paulraj (2009); Holt and Ghobadian (2009); Wu et al. (2011); Lin (2013); |

| | | |
|---|---|---|
| | | Diabat and Govindan (2011); Govindan et al. (2015a, 2015b) |
| Patent Numbers on Green/Eco Products | Improvement with patent number on green products/service | Damanpour and Wischnevsky (2006); Wu et al. (2011) |
| Life Cycle Costing | Comparative cost assessments made over a specified time period, taking into account all relevant economic factors for product through to end of life, or end of interest in the asset | Wee et al. (2011); Hsu et al. (2013) |
| LCA-Life Cycle Assessment | The standardized process to evaluate environmental aspects and potential impacts of a product system through all life phases. | Srivastava, (2007); Cherrafi et al. (2018); Noh and Kim (2019); Sellitto et al. (2019); Alvarez-Rodriguez et al. (2019) |

**Table 3: Linguistic Variables for fuzzy ANP**

| Linguistic Variables | Scale of Fuzzy Number | Scale of Reciprocal Fuzzy Number |
|---|---|---|
| Equal Importance Level | (1, 1, 1) | (1/1, 1/1, 1/1) |
| Moderately More Important Level | (2, 3, 4) | (1/4, 1/3, 1/2) |
| Strongly More Important Level | (4, 5, 6) | (1/6, 1/5, 1/4) |
| Very Strongly More Important Level | (6, 7, 8) | (1/8, 1/7, 1/6) |
| Extremely More Important Level | (8, 9, 9) | (1/9, 1/9, 1/8) |

**Table 4: Fuzzy Linguistic Scale for Performance Scores**

| Linguistic terms | Triangular fuzzy numbers |
|---|---|
| Very Good (VG) | (0.75,1.0,1.0) |
| Good (G) | (0.5,0.75,1.0) |
| Average (A) | (0.25,0.5,0.75) |
| Bad (B) | (0,0.25,0.5) |
| Very Bad (VB) | (0,0,0.25) |

**Table 5: Respective Weights of Criteria and Measurements, and Performance Scores**

| Criteria | Weights of Criteria | Measurements | Weights of Measurements | Individual Weights | Performance Scores | Scores | Collective Scores |
|---|---|---|---|---|---|---|---|
| Quality Management | 0.301 | | | | | | 0.223 |
| | | Customer Rejection Rate | 0.097 | 0.029 | 0.795 | 0.023 | |
| | | Yield Rate of Product | 0.223 | 0.067 | 0.875 | 0.059 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Percentage of Defective Items | 0.148 | 0.045 | 0.811 | 0.036 | |
| | | Environmental Quality Management | 0.102 | 0.031 | 0.546 | 0.017 | |
| | | Satisfaction of Employees in Green Operations | 0.087 | 0.026 | 0.811 | 0.021 | |
| | | Poka-Yoke Equipment | 0.075 | 0.022 | 0.204 | 0.005 | |
| | | Continuous Improvement System | 0.102 | 0.031 | 0.653 | 0.020 | |
| | | Scrap Rate | 0.083 | 0.025 | 0.843 | 0.021 | |
| | | Rework Rate | 0.085 | 0.025 | 0.842 | 0.021 | |
| Efficiency Management | 0.170 | | | | | | 0.126 |
| | | Overhead Expense | 0.177 | 0.030 | 0.795 | 0.024 | |
| | | Operating Expense | 0.384 | 0.065 | 0.749 | 0.049 | |
| | | Capacity Utilization | 0.243 | 0.041 | 0.701 | 0.029 | |
| | | Energy Consumption | 0.197 | 0.033 | 0.733 | 0.024 | |
| Green Production / Manufacturing | 0.322 | | | | | | 0.246 |
| | | Redefinition of Operational Processes | 0.032 | 0.010 | 0.780 | 0.008 | |
| | | Minimizing the use of Toxic and Hazardous Raw Materials | 0.061 | 0.020 | 0.827 | 0.016 | |
| | | Recyclable Raw Materials | 0.039 | 0.012 | 0.747 | 0.009 | |
| | | Recycled Raw Materials | 0.039 | 0.012 | 0.747 | 0.009 | |
| | | Waste and Pollution and Tracking Devices | 0.045 | 0.014 | 0.843 | 0.012 | |
| | | Structure for Easy Disassembly | 0.049 | 0.016 | 0.732 | 0.012 | |
| | | Monitoring and Maintenance System | 0.037 | 0.012 | 0.577 | 0.007 | |
| | | Inventory Levels | 0.105 | 0.034 | 0.794 | 0.027 | |
| | | Reduction in Operation Steps | 0.043 | 0.014 | 0.701 | 0.010 | |
| | | Minimizing the Amount of Hazardous Processes within Manufacturing | 0.038 | 0.012 | 0.858 | 0.011 | |
| | | Minimizing the Quantity of Hazardous Equipment and Devices | 0.031 | 0.010 | 0.826 | 0.008 | |
| | | Minimizing Health & Safety Risks | 0.087 | 0.028 | 0.686 | 0.019 | |
| | | Adapting Eco/Green Technology | 0.033 | 0.011 | 0.795 | 0.008 | |
| | | Simplifying the Assembling Operations | 0.051 | 0.016 | 0.812 | 0.013 | |
| | | Scheduling Production for Waste Reduction | 0.055 | 0.018 | 0.717 | 0.013 | |
| | | Designing Processes to be more energy efficient | 0.052 | 0.017 | 0.749 | 0.013 | |
| | | Designing Processes to Minimize Waste | 0.059 | 0.019 | 0.827 | 0.016 | |
| | | Minimizing Pollution Related to Noise | 0.031 | 0.010 | 0.593 | 0.006 | |
| | | Using Renewable Energy based resources | 0.047 | 0.015 | 0.747 | 0.011 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Investment in Green/Eco Machinery and Technology | 0.035 | 0.011 | 0.826 | 0.009 | |
| | | Collaboration with Customers on Green Production/Manufacturing | 0.031 | 0.010 | 0.858 | 0.008 | |
| Eco-Packaging | 0.102 | | | | | | 0.085 |
| | | Minimizing Toxic and Hazardous Materials within Packaging | 0.256 | 0.026 | 0.858 | 0.022 | |
| | | Recyclable items in Packaging | 0.120 | 0.012 | 0.842 | 0.010 | |
| | | Recycled items in Packaging | 0.124 | 0.013 | 0.827 | 0.010 | |
| | | Cooperation with Customers for Eco-Packaging | 0.096 | 0.010 | 0.904 | 0.009 | |
| | | Cooperation with Suppliers for Eco-Packaging | 0.104 | 0.011 | 0.873 | 0.009 | |
| | | Using Eco-Labels in Packaging Process | 0.201 | 0.020 | 0.764 | 0.016 | |
| | | Labelling for Retrieval Purpose | 0.099 | 0.010 | 0.764 | 0.008 | |
| Green Design | 0.105 | | | | | | 0.080 |
| | | Minimizing the Consumption of Energy | 0.081 | 0.009 | 0.764 | 0.006 | |
| | | Using Reused Materials within New Designs | 0.046 | 0.005 | 0.702 | 0.003 | |
| | | Using Recycled Materials within New Designs | 0.054 | 0.006 | 0.718 | 0.004 | |
| | | Minimizing the use of resources and generation of waste | 0.041 | 0.004 | 0.733 | 0.003 | |
| | | Minimizing Hazardous Materials and Processes | 0.063 | 0.007 | 0.857 | 0.006 | |
| | | Less Volume for Storage | 0.106 | 0.011 | 0.780 | 0.009 | |
| | | Simplifying the installation and setup to save Energy | 0.064 | 0.007 | 0.749 | 0.005 | |
| | | Extending Product/Service Life Duration | 0.168 | 0.018 | 0.827 | 0.015 | |
| | | Reducing Raw Material Consumption | 0.042 | 0.004 | 0.764 | 0.003 | |
| | | Considering Remanufacturing within Design | 0.044 | 0.005 | 0.686 | 0.003 | |
| | | Concurrent Engineering | 0.036 | 0.004 | 0.609 | 0.002 | |
| | | Collaboration with Customers on Green Design | 0.040 | 0.004 | 0.842 | 0.004 | |
| | | Collaboration with Suppliers on Green Design | 0.040 | 0.004 | 0.873 | 0.004 | |
| | | Patent Numbers on Green/Eco Products | 0.060 | 0.006 | 0.764 | 0.005 | |
| | | Life Cycle Costing | 0.058 | 0.006 | 0.748 | 0.005 | |
| | | LCA-Life Cycle Assessment | 0.057 | 0.006 | 0.702 | 0.004 | |
| **OVERALL PERFORMANCE SCORE FOR OPERATIONAL ACTIVITIES** | | | | | | 0.760 | 0.760 |