

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

KAZANCOGLU, Y., SAGNAK, M., KAYIKCI, Yasanur <<http://orcid.org/0000-0003-2406-3164>> and KUMAR MANGLA, S.

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

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## 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

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3 al. (2011) provided a framework to show the most significant interactions among green  
4 performance and activities by using the criteria of customer satisfaction, efficiency,  
5 environmental cost, waste and quality. This was evaluated by adopting a case-study approach.  
6 Chuang (2014) defined operational performance with four factors, namely, green recycling,  
7 green packaging, green using and green manufacturing. In addition, these criteria are divided  
8 into nine main criteria and 43 sub criteria where an AHP-based model was used to assess the  
9 operational performance. Jabbour et al. (2015) proposed a framework to study relationships  
10 among green activities, operations and environmental performances using five criteria - green  
11 design, green procurement, environmental management, environmental collaboration with  
12 customers and recovery of investment; this was also evaluated by adopting a case-study  
13 methodology. Chaudharya and Chanda (2015) presented an ANP-based methodology to  
14 evaluate and measure the performance in GSCM using six criteria - eco design, green  
15 purchasing, internal environmental management system, green packaging, internal recovery  
16 and relations with customers. Sehnem et al. (2019) analyzed critical success factors for  
17 improving sustainable supply chain performance through operational excellence with the  
18 adoption of the circular economy. Gólcher-Barguil et al. (2019) presented the development of  
19 conceptual framework and mathematical formulations to measure operational excellence. Many  
20 examples can be given, but it is crucial to conceptualize which criteria will improve overall  
21 operational performance in GSCM. Therefore, there is a need to develop a framework.  
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29 In this research, five criteria, and 57 measurements are adopted to propose a framework to  
30 measure the operational performance in GSCM as seen in Table 1. Five criteria are listed as  
31 follows: Quality Management, Efficiency Management, Green Production / Manufacturing,  
32 Eco-Packaging and Green Design.  
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### 35 [Table 1 Near Here]

#### 36 3.1. *Quality Management*

37 Increase in quality in terms of products and processes has a greater impact in improving  
38 operational performance (Zhu et al., 2008; Jabbour et al., 2015). Achieving less rejection rate  
39 (Azevedo et al., 2011), yield rate (Azevedo et al., 2011), defect rate (Diabat et al., 2013), rework  
40 rate (Henaio et al., 2019), scrap rate (Zhu et al., 2005; Zhu et al., 2007) through better  
41 management practices will improve quality. Increase in quality as an ultimate criterion of  
42 operational performance has been addressed by various researchers (see Table 2).  
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#### 47 3.2. *Efficiency Management*

48 Increasing efficiency is not an easy task but it has a great potential to reach a higher degree of  
49 operational performance (Duarte et al., 2011; Azevedo et al., 2011). Using environmentally  
50 friendly materials and machines can reduce overhead and operating expenses, improve capacity  
51 utilization and increase energy efficiency (Dubey et al., 2015; Tseng et al., 2019).  
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#### 55 3.3. *Green Production/Manufacturing*

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

### 14 3.4. *Eco-Packaging*

16 Eco-packaging has been used as a criterion of operational performance by various researchers  
17 (see Table 2). Eco-packaging implies any changes made by product manufacturers or service  
18 providers to minimize the environmental impacts of packaging in the processes, products or  
19 services to consumers (Chuang, 2014). Packaging material can often cause a massive amount  
20 of waste because it becomes useless after the product is purchased. Therefore, during the  
21 operational processes, the use of recyclable (or biodegradable, recycled, renewable) materials,  
22 non-toxic and hazardless packaging materials, or refillable (or reusable) environmentally  
23 friendly packaging is important in order to reduce the waste caused by packaging (Zhu et al.  
24 2007; Chuang, 2014).

### 29 3.5. *Green Design*

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

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

45 [Table 2 Near Here]

## 47 4. Methodology

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

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3 simultaneously with the aid of FMEA. In addition, various stochastic models can be  
4 implemented for reliability management and for FMEA in different processes of the company.  
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#### 6 7 • OHSAS for Health & Safety

8 Occupational health and safety is a crucial topic, especially in the hot dip galvanizing sector,  
9 where both inherent processes and equipment may be the source of risks. Some of the  
10 significant risks can be listed as the splash of molten zinc particles during the immersion of  
11 materials in the molten zinc, risks related to cranes in terms of possible falls of improperly  
12 stabilized material, risks related to splash of acid from acid tanks plus the potential risk of high  
13 voltage electricity. Therefore, these risks require a systematic approach in their handling.  
14 OHSAS can be a starting point to cope with occupational health and safety issues and to  
15 contribute to social sustainability.  
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19 Green Design criterion has two performance scores that need to be improved. These relatively  
20 weak scores belong to Considering Remanufacturing within Design with an individual score of  
21 0.686 and Concurrent Engineering with an individual score of 0.609. Matrix Organization  
22 Structure is proposed to institutionalize the Green Design.  
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#### 25 26 • Matrix Organization Structure for Organizational Structure

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

49 Nowadays, organizations are forced to pay attention to environmental considerations in  
50 conjunction with social and economic concerns. Businesses have started to become greener in  
51 their supply chain activities to decrease or eliminate waste and to protect natural resources. The  
52 term, green supply chain management (GSCM), has evolved as a concept to include green  
53 processes in supply chain activities; i.e. design, logistics, purchasing, packaging,  
54 manufacturing, marketing and reverse logistics.  
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58 The assessment of GSCM performance requires a holistic view of the entire supply chain.  
59 GSCM performance can be appraised by inclusion of both quantitative and qualitative factors.  
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3 Since one of the critical issues regarding GSCM practices is the operations, becoming green in  
4 the operational side of activities is important.  
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7 In this paper, a framework is proposed to evaluate the operational performance of a hot dip  
8 galvanizing company. The framework includes five criteria, namely Quality Management,  
9 Efficiency Management, Green Production / Manufacturing, Eco-Packaging, and Green  
10 Design. Firstly, the weights of the criteria and the respective measurements were found by  
11 Fuzzy ANP; then the overall operational performance score was found by the Weighted Scoring  
12 Method. The performance scores regarding each criterion were multiplied with the respective  
13 criterion weights to get an overall operational performance of the organization.  
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17 “Green Production/Manufacturing” was found to be the most important criterion followed by  
18 “Quality Management” and “Efficiency Management” with weights of 0.322, 0.301 and 0.170,  
19 respectively. Overall, “Yield Rate of Product” was found to be the most important measurement  
20 for evaluating the operational performance followed by “Operating Expense” with weights of  
21 0.067 and 0.065, respectively. The overall performance score for operational activities was  
22 found to be 0.760, which means the company is operating at 76% efficiency.  
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25 This work has some limitations, such as the involvement of human beings in decision-making.  
26 This can be subjective and cannot be classified as definitive. Thus, the only limitation deemed  
27 to be valid for the study is the acquisition of data as a result of subjective evaluations.  
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30 This work conducts a case study in a manufacturing company in the Turkish context. Any future  
31 research may include the evaluation of green operational performance with modified criteria in  
32 different sectors with a modified framework in different nations The listed criteria may also be  
33 tested empirically in future. Further, the operational excellence of GSCM may also be evaluated  
34 in a circular economy environment.  
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**Table 1: Proposed framework for operational performance of GSCM**

<b>Operational Performance</b>				
<b>Quality Management</b>	<b>Efficiency Management</b>	<b>Green Production/Manufacturing</b>	<b>Eco-Packaging</b>	<b>Green Design</b>
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
<b>Quality Management</b>		
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)
<b>Efficiency Management</b>		
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)
<b>Green Production/Manufacturing</b>		
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)
<b>Eco-Packaging</b>		
Minimizing Toxic and Hazardous Materials within Packaging	Non-toxic and hazardless packaging materials are used	Chuang (2014); Chaudhary and Chanda (2015)



1	Recyclable items in Packaging	Recyclable materials are used in packaging	Chuang (2014)
2	Recycled items in Packaging	Recycled materials are used in packaging	Chuang (2014)
3	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)
4	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)
5	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)
6	Labelling for Retrieval Purpose	Material packages are labeled for storage and retrieval.	Shang et al. (2010)
7	<b>Green Design</b>		
8	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)
9	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)
10	Using Recycled Materials within New Designs	Using eco-friendly and recycled materials during new product designs	Beamon (1999), Zhu (2008); Rostamzadeh et al. (2015)
11	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)
12	Minimizing Hazardous Materials and Processes	Designs focused on minimizing the usage and inclusion of hazardous materials and production processes	Shang et al. (2010)
13	Less Volume for Storage	Design the product to use less area to store	Chaudhary and Chanda (2015)
14	Simplifying the installation and setup to save Energy	Design the product for easy setup in most energy efficient way	Chaudhary and Chanda (2015)
15	Extending Product/Service Life Duration	Design service/product for a longer life cycle	Chuang (2014)
16	Reducing Raw Material Consumption	Designing product to reduce material use	Zhu, et al. (2005); Zhu et al. (2007); Zhu et al. (2013)
17	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)
18	Concurrent Engineering	Practice of incorporating various values to design a product at early development stages	Giovanni and Vinzi (2012)
19	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)
20	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	
<b>OVERALL PERFORMANCE SCORE FOR OPERATIONAL ACTIVITIES</b>						<b>0.760</b>	<b>0.760</b>

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