A best-worst-method-based performance evaluation framework for manufacturing industry

Sharfuddin Ahmed Khan
Industrial Engineering and Engineering Management Department
College of Engineering, University of Sharjah
Sharjah - United Arab Emirates
Email: skhan@sharjah.ac.ae

Simonov Kusi- Sarpong
Southampton Business School, University of Southampton
Southampton S017 1BJ, United Kingdom
Email: simonov2002@yahoo.com

Iram Naim
Department of Computer Sci. & Informantion Tech.
Faculty of Engineering & Technology,
M.J.P. Rohikhand University, Bareilly (U.P.), India
Email: iram.naim03cs@gmail.com

Hadi Badri Ahmadi
Department of Industrial Engineering and Management,
National Taipei University of Technology, Taipei, Taiwan
Email: hadi.badri.ahmadi@gmail.com

Adegboyega Oyedijo
Hull University Business School, The University of Hull,
Hull, United Kingdom
Email: a.oyedijo@hull.ac.uk

A best-worst-method-based performance evaluation framework for manufacturing industry

Abstract

Purpose: The purpose of paper is to develop a performance evaluation framework for manufacturing industry to evaluate overall manufacturing performance.

Design/methodology/approach: The Best Worst Method (BWM) is used to aid in developing a performance evaluation framework for manufacturing industry to evaluate their overall performance.

Findings: The proposed BWM-based manufacturing performance evaluation framework is implemented in an Indian steel manufacturing company to evaluate their overall manufacturing performance. Operational performance of the organization is very consistent and range between 60% to 70% throughout the year. Management performance can be seen high in percentage in the first two quarter of the financial year ranging from 70% to 80% whereas a slight decrease in the management performance is observed in the 3rd and 4th quarter ranging from 60% to 70%. The social stakeholder performance has a peak in first quarter ranging from 80% to 100% as at start of financial year.

Originality/value: This paper utilized BWM, a MCDM method in developing a performance evaluation index that integrates several categories of manufacturing and evaluates overall manufacturing performance. This is a novel contribution to BWM decision-making application.

***Keywords*:** Performance evaluation; best worst method; manufacturing; operations; management; social and stakeholders.

1. Introduction

Manufacturing is the process of transforming raw material into finished products (Kalpakjian and Schmid, 2016). This core manufacturing activity is central to the performance and success of the firms (Malek and Desai, 2019). This therefore requires continuous performance measurement and improvement by organizations to remain highly competitive (Rehman et al., 2018). Developing manufacturing performance evaluation framework is significant for strategy management and plays a critical role in achieving competitive success (Yang *et al*., 2009). Due to globalization and ever-rising customer demand, manufacturing organizational managers and decision makers are usually faced with many obstacles in managing and evaluating their manufacturing process performance. In addition, managers and decision makers usually receive too much information related to their manufacturing processes from scattered and isolated sources (Jain *et al*., 2011). This scattered information is neither integrated nor good enough to provide guidelines for improvement. Fast decision-making and on the spot corrective actions are now becoming essential for manufacturing organizations to remain highly competitive. Therefore, in order to evaluate and improve the overall manufacturing performance, there is the need for a manufacturing performance evaluation framework that is effective and efficient for today's manufacturing organizations.

Manufacturing performance measurement framework should provide decision makers and managers with some basis for continuous measurement and improvement and in line with digitalization. Performance evaluation for manufacturing organizations is an essential starting point to achieve excellence (Kochhar and Eguia, 1998). Performance evaluation framework is a system or set of matrices utilized to quantify both efficiency and effectiveness of criteria and sub-criteria (Khan *et al*., 2019). Neely *et al*. (1997) argued that, evaluation of performance is basically a set of process to measure activities (actions) and quantifying its efficiency and effectives with associated targets (Okoshi *et al*., 2019). Integration of operational criteria and their associated sub-criteria in evaluating overall manufacturing performance is essential for improvement and benchmarking. Digitalization have made it easier for data collection and storage, and, have made it possible for organizations to evaluate their overall manufacturing performance in real time. This also allows decision makers and managers to take appropriate decisions on time. Furthermore, instant decision making to identify and improve underperformed criteria or strategic and operational areas, reduces manufacturing cost and avoid delays in fulfilling customer demands.

Several integrated performance measurement frameworks have been developed in the recent past and have tried to combine more than one performance criterion (see Khan *et al*., 2019; Khan *et al*., 2018; Rehman *et al*., 2018; Hassan *et al*., 2017; Khan *et al*., 2016). An integrated performance measurement framework that addresses the many shortcomings of the previously developed frameworks is required. However, there exist several important issues that are essential to be included in the evaluation of manufacturing performance. For example, integration of all operational performance criteria and sub- criteria, utilization of real time data collection and real time performance evaluation, and instant manufacturing performance evaluation that helps managers and decision makers initiating corrective actions, just to mention a few of them.

Existing manufacturing systems are not efficient and flexible enough to update critical information related to key performance indicators on time. Traditional frameworks are mainly based on financial measures and evaluate performance mainly on financial terms. These frameworks evaluate performance based on past performance parameters that lead the managers and decision makers to ignore long-term and continuous improvement (Ghalayini *et al*., 1997; Liu, 2008; Önüt *et al*., 2008; Yang *et al*., 2009). These existing manufacturing performance measurement frameworks are not capable of adopting dynamic and challenging manufacturing environment. As argued by Yang *et al*. (2009), effective manufacturing performance evaluation framework must provide a roadmap of continuous improvement and should be explicit and objective. In addition, there is the need for an integrated manufacturing performance evaluation framework for aiding continuous improvement to remain highly competitive.

The aim of this paper is to introduce a performance evaluation framework for manufacturing industry. This framework is modelled aided by the best-worst method (BWM). The framework aids the evaluation of the overall manufacturing performance and provides guidelines to managers and decision makes for continuous improvement, highlighting the under-performed functions and criteria. Moreover, the proposed performance evaluation framework will allow managers to monitor, control, and take instant action to improve overall manufacturing system. The proposed framework provides an opportunity to decision makers and managers to evaluate their manufacturing performance by integrated criteria and sub-criteria.

Now a days ways of making decisions has been changed. It is important to incorporate decision makers' knowledge and experience in decision-making. Manufacturing is core of any business success and it is essential to evaluate manufacturing performance effectively and efficiently. Evaluation of overall manufacturing performance will help organizations to remain competitive and fulfill customers demand more effectively. However, literature is lacking in evaluating overall manufacturing performance. Therefore, this study will propose manufacturing performance index that incorporated decision maker's knowledge and experience and evaluated overall manufacturing performance.

Therefore, the specific objectives of this paper are to:

i) Review literature to identify and validate criteria and sub-criteria that are essential for manufacturing organizational performance evaluation.

ii) Develop a performance evaluation framework for manufacturing industry based on BWM.

iii) Practical implementation of the proposed performance evaluation framework within a case manufacturing company.

1.1 Novelty and Contribution

The contributions of this paper are manifold. First, the focus on a manufacturing performance evaluation has only seen very limited attention in the literature and in different aspect such as in the context of Industry 4.0; green lean performance in manufacturing industries; environmental performance of manufacturing organizations (see: Singh *et al.*, 2020; Kamble *et al.*, 2020; Marulanda-Grisales and Figueroa-Duarte, 2020). This paper adds to this emerging investigation by introducing an integrated overall manufacturing performance index to address this gap. Second, it develops a framework to evaluate overall manufacturing performance in the context of emerging economy, India. In addition to that, literature in limited and not many authors developed any framework that evaluates overall manufacturing performance in the context of social, operational, and management. Therefore, this work pioneers research in this direction. Third, this is first time BWM is utilized in aiding development of performance evaluation index that integrates several factors and criteria of manufacturing and evaluates their overall manufacturing performance. This is a novel contribution to BWM decision-making application.

The reminder of the paper is organized as follows. Section 2 will provide brief overview of literature in the field of PMS in general and application of BWM in performance measurement. Section 3 will discuss the research methodology and overview of BWM. Section 4 shows the case application of the proposed manufacturing performance evaluation index system. Section 5 discusses the results and implications, and, lastly, Section 6 conclude the study and provides future research directions and limitations.

2. Literature background

2.1 Performance Measurement Systems and Multi-Criteria Decicion Making

Performance measurement (PM) is the process of quantitatively or qualitatively evaluating the effectiveness and efficiency of organisational activities (Neely *et al*., 1995). Performance measurement systems (PMS) is a set of performance measures that are taken into consideration when evaluating business organizations performance (Carlsson-Wall *et al*., 2016). PMS plays a significant role at organizational, supply chains and national levels as they influence decisions at these levels (Laihonen and Pekkola, 2016; Van Hoek, 1998).

Waggoner *et al*. (1999) argued that, internal factors such as peer pressure, power relationships and search for legitimacy; and external factors including legislation and information technology, shape organizational PMS. Akyuz and Erkan (2010) argued that, PMS are information systems that transform input (data) into outputs (performance measures) and are then employed to assess performance and provide feedback. A well-designed PMS can help organizations in achieving improvement in overall supply chain, implementation of supply chain strategy, control and decision making at strategic, tactical, and operational level (Bhagwat and Sharma, 2009; Gunasekaran *et al*., 2004; Mondragon *et al*., 2011).

A large number of firms have identified the importance of financial and non-financial performance measures, but have not been able to represent them in a balanced framework. The metrics, which are employed in performance measurement should capture the organizational performance nature (Gunasekaran *et al*., 2004). In order to achieve a successful and efficient performance measurement, measurement targets should follow organizational objectives. Also, metrics that have been selected should demonstrate a balance among financial and non-financial measures (Gunasekaran *et al*., 2004), It can be related to strategic, tactical and operational levels of decision-making and control (Lima-Junior and Carpinetti, 2017; Seuring, 2013). Performance evaluation literature consist of variety of studies, including metrics conceptual frameworks (Gunasekaran *et al*., 2001), identification of measures using surveys (Gunasekaran *et al*., 2004), case studies (Cuthbertson and Piotrowicz, 2011) and quantitative models to support the performance evaluation process (Chithambaranathan *et al*., 2015).

Several number of performance measurement techniques and approaches have been developed within the past decade to assess the performance of supply chain from diverse categories. An efficient PMS is in high demand in order to assist corporations in order to obtain their business targets by monitoring the effectiveness of the deployment of their new strategies (Jayaram *et al*., 2014). According to a study carried out by Lima-Junior and Carpinetti, (2017), multi-criteria decision-making (MCDM) models are the most applied methods for evaluating manufacturing supply chain performance (50.0%), followed by mathemathical programing (21.4%), artificial intelligence (11.9%), simulation (6.0%) and statistical techniques (4.8%). Among the MCDM applied, AHP (Analytic Hierarchy Process) and DEA (Data Envelopment Analysis) are the mose employed thechniques for supporting SCM performance evaluation and measurement (Lima-Junior and Carpinetti, 2017). Based on a research carried out by Neely *et al*. (2001), financial PMS, which mainly focus on financial measures, have been criticized because of neglecting non-financial metrics. Rehman *et al*. (2018), in their study employed AHP and DMAIC (define, measure, analysis, improve and control) methodology to model a novel SCPMI system in order to measure and improve supply chain performance in the context of an emerging economy nation automobile manufacturing firm. In this study, the authors employed a mix of financial and non-financial measures.

2.2. Best Worst Method and Manufcaturing Performance Evaluation

The use of Best-worst method can be found in the manufacturing domain. According to Malek and Desai (2019), the decision making in manufacturing organizations considering the triple bottom line (economic, environmental and social) dimensions is very complex when prioritizing and selection. The best worst method is one of the best methods used by the researchers to ease the difficulties in prioritizing the multi-criteria and multi-dimensional nature of sustainable manufacturing elements. The performance and success of manufacturing industries depend upon the adoption and use of emerging manufacturing technologies. Such a leading additive manufacturing technology and its role in sustainable benefits has been discussed (Niaki *et al*., 2019).

The Best-worst method is also a potential method for performance analysis in different domains. Financial ratios are the prominent parameters for examining the performance of organizations. Alimohammadlou and Bonyani (2018) used Dynamic analysis of performance instead of cross- sectional analysis for accurate examination of financial performance of an organization compared with multi criteria decision making. Establishing the specification for any project is a complex and tedious task, as in any project there are a number of hidden information, which is generally ignored by specifier assuming that it is well understood. Such an assumption may include fuzzy terms like hidden fuzzy terms (HFTs). An algorithm proposed in Asadabadi *et al.* (2019) deals with the extraction of the hidden fuzzy terms using fuzzy interference system and applies the best worst multi-criteria decision making to deliver the product and evaluate the performance of provider.

Green human resource management (GHRM) has become an important tool for environmental management (Adjei-Bamfo *et al*., 2019). A study on performance of manufacturing organizations considering GHRM has been given in Gupta (2018). Generally, the port choice and port performance are treated as different entities. A research work demonstrating port performance vis a vis port choice has been discussed in Rezaei *et al*. (2019). In this study, factors affecting port choice have been included in port performance studies and the importance of these factors is assessed aided by the best worst method. A composite index (CI) has been developed by Raj and Srivastava (2018) in order to examine the performance of aircraft manufacturing organizations. This study uses Fuzzy best worst multi-criteria decision-making technique. Research and development (R&D) of any organization provides it an extra edge in terms of its competition, productivity and growth. A study was conducted by Salimi and Rezaei (2018) to investigate the performance of R&D in organizations aided by the best worst method and identified the importance of R&D measures.

Best worst method (BWM) and Fuzzy interference system (FIS) was utilized in Torbati *et al*. (2018) to evaluate the performance of insurance branches in Iran. Various parameters like insurance costs, premium income, deferred claims, marketing cost, customer satisfaction etc. were analyzed to strengthen the study. The operational performance of four power grids in China has been studied in You *et al*. (2017). This study uses hybrid multi criteria decision-making framework for examining the sustainability of grids. Best worst method was also implemented to rank the operational performance of different grids. The importance of energy storage system is increasing along with the increase in share of renewable energy for reliable and stable grid. A comprehensive framework utilizing multi criteria decision-making and fuzzy Delphi approach has been developed in Zhao *et al*. (2018a) for selection of appropriate energy storage system.

China is underway of reform of transmission and distribution tariffs due to various emerging electricity-selling companies. Thus, it becomes prudent for electricity grid companies to make up their operational performance. Zhao *et al*. (2018b) provides a model of multi-criteria decision making integrated with fuzzy Delphi and best worst method in order to examine the performance of grid companies. A paper by Abouhashem Abadi *et al.* (2018) provides a framework utilizing SWOT model and best worst method for the development of medical tourism industry in Iran.

In today's era, corporate sustainability pressures play a significant role in decision making of organizations. The framework developed in (Bai *et al.*, 2019) suggests socially sustainable attributes for decision making by use of best worst method and TODIM. Supply chain management and its sustainable growth is becoming popular. In addition, there is increased awareness among organizations toward selecting suppliers considering environmental and social concerns of customer requirements. In another paper, Garg and Sharm (2018) proposed a model based on best worst method for the selection of sustainable outsourcing partners. The development of innovation and technology is of utmost important to organizations especially for those in the aerospace and remotely – piloted helicopters due to their involvement in high-level complexity and cost. A study by Ghaffari *et al*. (2017) highlighted on the key success factors in technological development of RPH industry.

A framework has been developed by Mahmoudi *et al.* (2019) using best worst method for examining the sustainability and evaluating the criteria considering the social and environmental dimensions in addition to the economic criteria. Water security has become a great challenge due to rapid increase in urbanization and industrialization. Sustainability of water is of utmost importance and measured through various parameters. An integrated framework utilizing multi-criteria decision-making, the best worst method, has been introduced in Nie *et al.* (2018) covering the dimensions related to sustainability of water security. Oil and gas are the two most used energy resources in the world, their excessive use has adverse effect on environment and society. Thus, sustainable oil and gas supply chain management has become an important aspect for eradicating such problems. The external forces such as economic and political stability, competition etc. are the driving forces for supply chain management practices. A paper by Wan Ahmad *et al*. (2017) has analyzed the collective significance of such forces and used the best worst method for examining the data collected from two oil and gas companies.

3. Research Methodology

This study uses a single case study methodology to investigation the work. In this section, we will discuss the development of manufacturing performance evaluation index in detailed. All stages are simplified and illustrated in figure 1.

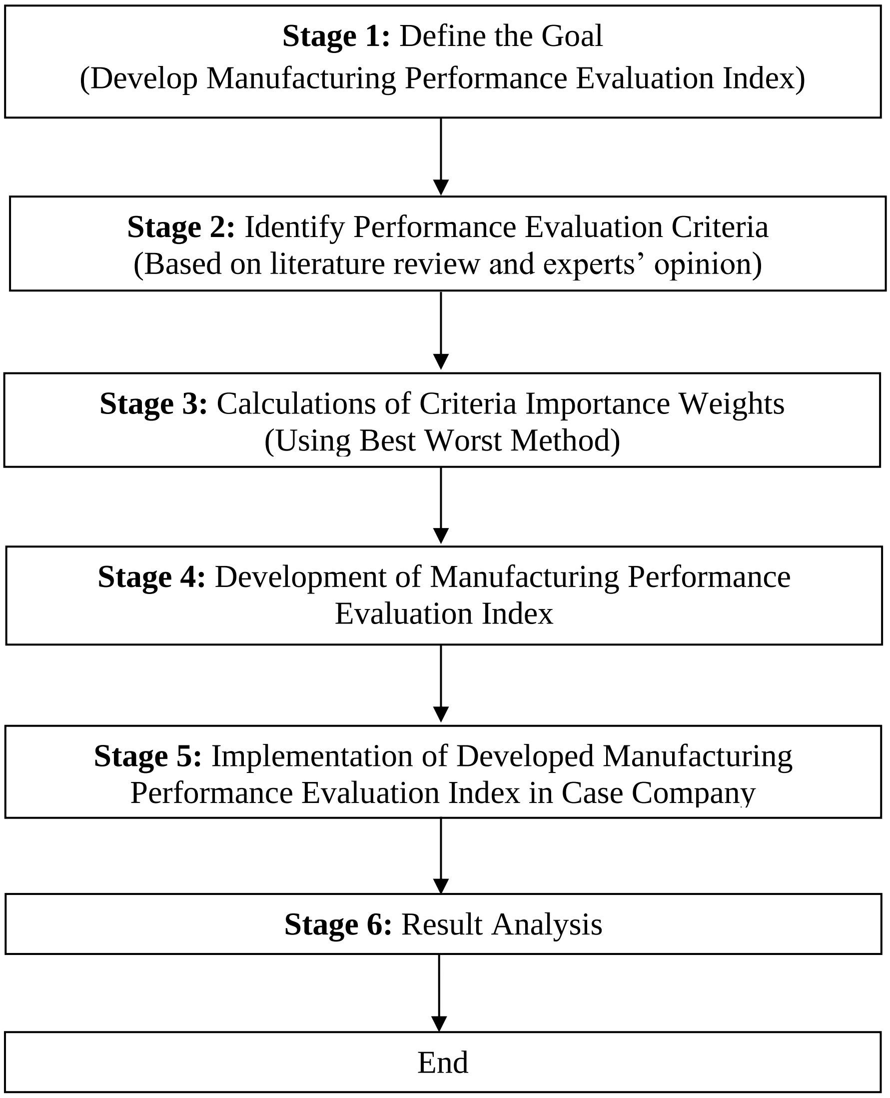

Figure 1: Step by Step Approach to Develop Manufacturing Performance Measurement Index

Stage 1: Define the Goal

In this stage, the goal of the study is set to inform the remaining stages. For example, to develop a performance evaluation index.

Stage 2: Identify Performance Evaluation Criteria

In this stage, related performance evaluation criteria are identified from the literature and refined using experts' opinion.

Stage 3: *Calculations of Criteria Importance Weights using BWM*

In this stage, the performance evaluation criteria identified in stage 2 are evaluated to determine the importance weights. In this study, the Best Worst Method (BWM), introduced by Rezaei, (2015) was selected and utilized to aid the evaluation. BWM is a recently developed MCDM method for identifying criteria weights (Rezaei, 2015). BWM has many advantages over the other mostly used MCDA techniques (Loh et al., 2020). Among the many MCDM techniques available in the literature for determining criteria/factors weights etc. such as Analytic Hierarchy Process (AHP) that was first introduced by Saaty in 1980 (Saaty, 1980), Full Consistency Method (FUCOM) that is recently introduced by Pamučar, Stević, and Sremac in 2018 (Pamučar, Stević, and Sremac, 2018), Level Based Weight Assessment (LBWA) which is first introduced by Žižović and Pamucar in 2019 (Žižović and Pamucar, 2019), Ordinal Priority Approach (OPA) that is proposed in last year by Ataei (Ataei et al. 2020), Stepwise Weight Assessment Ratio Analysis (SWARA) was introduced by Kersuliene et al. in 2010 (Kersuliene, Zavadskas, and Turskis, 2010), AHP happens to be the most widely used technique. AHP is widely used in group decision-making (Lin et al. 2020; Zhang et al. 2021; Yu et al. 2021). Although the literature suggests the heavy presence and adoption of AHP in many studies, unfortunately, it results are compromised (Orji et al., 2020). This compromise final solution of AHP is due to the many inconsistencies which results from the huge number of pairwise comparisons making the problem much more complex to handle (see e.g. Büyüközkan and Guleryuz, 2016). This problem complexity further amplifies with increased number of criteria (Kusi-Sarpong et al., 2016). To deal with these inconsistencies originated from the complexity and amplification of the pair-wise comparisons, and provide consistent solutions, the BWM is introduced and deemed the most appropriate MCDM technique.

BWM when compared to AHP statistically, Rezaei (2015) identified that, BWM results were highly consistent (Mi et al., 2019). Thus, BWM is preferable in performance over AHP from four principal areas including consistency, minimum violation, conformity, and total deviation (Rezaei, 2015; Mi et al., 2019). BWM is a vector-based approach which requires relatively less pairwise comparison data and inputs, which is its advantage over other heavily used MCDM such as AHP (Rezaei, 2016; Gupta *et al*., 2020). Another principal reason for selecting BWM over the others is the heavy applications of BWM in the academic literature (about 344 papers)[1], evidencing that it provides good results and hence have received strong acceptance among academics and practitioners. BWM has already been utilized in a number of real world problems such as social sustainability supply chain assessment (Badri Ahmadi *et al*., 2017), supply chain sustainability innovation (Kusi-Sarpong *et al*., 2019), eco-innovation for freight logistics sustainability (Orji *et al*., 2019), R&D performance measurement of companies' (Salimi and Rezaei, 2018), social sustainable supplier evaluation and selection (Bai *et al*., 2019), social media for supply chain social sustainability (Orji *et al*., 2020), enablers to supply chain performance (Gupta et al., 2020) and barriers and overcoming strategies to supply chain sustainability innovation (Gupta *et al*., 2020). These advantages motivated us to select and utilize BWM for this study.

BWM (Rezaei, 2015, 2016) is structured according to the following steps:

Step 1. Identifying decision criteria set. Thus, a number of criteria $\{c_1, c_2, c_3, \ldots, c_n\}$ that describes the decision is determined.

Step2. Decision makers determined best (B) criterion and worst (W) criterion.

Step 3. Based on a scale of 1 to 9, each decision maker is ask to elicit pairwise comparison of best criterion over all the other criteria. This results in a vector $\boldsymbol{A_B} = (a_{B1}, a_{B2}, a_{B3}, \ldots, a_{Bn})$.

Step 4. Similarly, as above, each decision-maker is asked to elicit pairwise comparison of all criteria over the worst criterion and this results in a vector of $\boldsymbol{A_W} = (a_{1W}, a_{2W}, a_{3W}, \ldots, a_{nW})^T$.

Step 5. Finally, the optimal weights of the criteria $(w_1{}^*, w_2{}^*, w_3{}^*, \ldots, w_n{}^*)$ are computed. This is completed by obtaining criteria weights so that the maximum absolute differences for all *j* can be minimized for $\{|w_B - a_{Bj}w_j|, |w_j - a_{jW}w_W|\}$. Therefore, the following minimax model is obtained:

$$\min max_j \{|w_B - a_{Bj}w_j|, |w_j - a_{jW}w_W|\}$$

Subject to

$$\textstyle\sum_j w_j = 1 \tag{1}$$

[1] https://bestworstmethod.com/wp-content/uploads/2020/07/BWM-bibliographical-database.pdf (Accessed: 16 May 2021) – Last updated 07 June 2021

$w_j \geq 0$, for all j

Problem (1) can be transferred to the following linear programming problem:

$$\min \xi^L$$

Subject to

$$|w_B - a_{Bj} w_j| \leq \xi^L, \text{ for all } j$$

$$|w_j - a_{jW} w_W| \leq \xi^L, \text{ for all } j \quad (2)$$

$$\sum_j w_j = 1$$

$w_j \geq 0$, for all j

Model (2), can be solved to obtain the optimal weights $(w_1{}^*, w_2{}^*, w_3{}^*, \ldots, w_n{}^*)$ and ξ^{L*}. The closeness of the consistency value of ξ^{L*} to zero, the better.

Stage 4: Development of Manufacturing Performance Evaluation Index

After determining the criteria importance weights using BWM as in stage 3, the proposed model is mathematically formulated using equation 3.

$$Y = \sum_{i=1}^{n} \alpha_i \left(\sum_{j=1}^{m} \beta_{ij} \, X_{ij} \right) \quad (3)$$

Where: Y = Manufacturing Performance Evaluation Index (%)

i = 1, 2 . . . n

j = 1, 2 . . . m

n = No. of category

m = Criteria set within each category

X_{ij} = Criteria j value for category i

α i = Weight (%) of category i

β ij = Weight (%) of criteria j for category i.

The model proposed considers all the elements of the category and criteria framework. In cases where some of the criteria or category information is/are unavailable, the model can simply adjust the Xij value by assuming its value is zero. This will further require renormalizing the relevant and remaining weights (β ij) using equation 4.

$$(\beta_{ij})' = \frac{\beta_{ij}}{\sum_{i}^{m} \beta_{ij}} \tag{4}$$

Where: $(\beta_{ij})'$ = New normalized weight of the criteria j for category i.

Stage 5: Implementation of the Performance Evaluation Index

In this stage, the proposed evaluation index model is implemented using archival or empirical data.

Stage 6: Result Analysis

The outcome from the implementation is analyzed to make meaning out of it to support decision-making and possible aid in the development of improvement implementation plans. In this paper, we will make this stage a section due to the fact that it plays very a central role.

4. Case study

4.1 Case problem description

The proposed manufacturing performance evaluation index is validated using a case study. The case manufacturing company was founded in the year 1976 in India represented as "company ABC". Company ABC manufactures steel- based castings and forgings for power plant equipment's, cement industry, steel industries, defense, ship building etc. The company produces various steel grade- based products to the tune of 10000 MT per year. It has ability to melt and process wide variety of steel grades right from plain carbon grade to creep resistant, super critical and high chromium stainless steel. Company ABC has various certifications like Quality Systems (ISO-9001), Environment (ISO-14001, Occupational Health & Safety (ISO-18001) and Energy Management System (ISO-50001). It also consists of various policies on scrap management, use of green technology, energy management etc. It has a strong work force of around 1800 employees at various cadres working across different functions. Company ABC is committed for delivering high quality product and total satisfaction of customer and so are interested to identify areas that they are not performing well to improve. They therefore agreed to pursue this exercise to achieve this goal.

Stage 1: Define the Goal

In this stage, our goal is to develop manufacturing performance evaluation index. This index will help organizations (in this case, the case manufacturing organization) to measure their overall manufacturing performance based on a set of criteria.

Stage 2: Identify Performance Evaluation Criteria

In this stage, we first identify some potential manufacturing performance evaluation criteria from the literature and subjected them to review by managers and experts from the case company. Our searched targeted several database such as science direct, wed of science, and google scholar. Different keywords and their combination were used in search such as "manufacturing performance", "manufacturing performance indicator", "manufacturing performance criteria" etc. All papers that are in line with the objectives and scope of our study were included and did not consider works, which are not peer-reviewed, unpublished papers, and graduate thesis. After several rounds of discussions and review by managers and experts (profile of experts can be found in table 2), we arrived with manufacturing performance evaluation criteria listing (3 category and 18 sub-category) which are shown in Table 1 with their brief descriptions.

Table 1: Manufacturing Performance Evaluation Criteria

S. No.	Categories	Criteria	Description
1	Operational (O)	Production rate (O_1)	This refers to the production of the right amount of product within a given time.
2		Productivity (O_2)	This refers to the production output over raw material/production input.
3		Flexibility (O_3)	This refers to the ability of the production line to be agile and to adjust (customize) the different aspects to produce the desired products.
4		Production Capacity (O_4)	This refers to the ability of a manufacturing system to fulfil market demand.
5		Machine Downtime (O_5)	This is the time period within which machine is down for maintenance or breakdown and affect production schedule
6		Machine Reliability (O_6)	This refers to machine availability or uptime over the production schedule time (total period the machine is required)
7		Cost (O_7)	This includes delivery cost, costs of production and different cost components that are related to manufacturing processes.
8		Quality (O_8)	This refers to the fit for purpose and aesthetics, the process parameters within the design specification limit to keep the

			quality of the part produced and to deliver the required specification of output.
9		Raw Material Quality (O_9)	Quality of raw material during manufacturing process
10	Social Stakeholders* (S)	*Employee Transfer (S_1)	This is the relocation of employees to various organizational working locations
11		*Employee Entertainment (S_2)	This refers to the organizing providing a well-organized entertainment activity to employees to ensure their psychological and mental health is healthier.
12		*Provision of employee accommodation (S_3)	This refers to the organizations providing employees with comfortable accommodations to take away the burden of housing to focus on the job.
13		*Market Competition (S_4)	This refers to the firm keeping a close eye on markets for similar products to overcome competitions.
14	Management (M)	*Business Expansion (M_1)	This refers to the organizations exploring other opportunities to expand their business in terms of new markets, new domains, and new technology.
15		Unavailability of Raw Material (M_2)	This refers to the lack of raw material from supplier or stock-out of material in stock.
16		*Occupational, health and safety (M_3)	This refers to the company mandating all it employees to comply with the occupational health and safety rules by using for example appropriate personal protective equipment.
17		On time delivery (M_4)	This is the manufacturing process able to meet production schedule.
18		Employees overtime (M_5)	This is employee/manpower usage after normal working hours required to meet production schedule.

* Added by experts and compiled from Hon (2005); ElMaraghy *et al*. (2009); Tunälv (1992); Mattias (2007); Rachna and Peter (2003); Wheelwright (1984); Gerwin (1987); and Khan and Zaidi (2012)

Stage 3: Calculations of Criteria Importance Weights

In this stage, the BWM is utilized to calculate the manufacturing performance evaluation criteria importance weights. Since the criteria have already been determined in stage 2, *step 1 of the BWM is omitted*. The profile of the experts who participated in the BWM is summarized in Table 2.

Table 2: Profile of experts involved in the BWM evaluation

Expert #	**Position**	**Department**	**Years of Experience**	**Responsibility**
1	Director	Central Planning	28	Advance planning and scheduling, strategic management of materials budget allocation, delivery schedules, prioritizing of orders etc.
2	General Manager	Production	18	Time estimation of Jobs, production capacity, resource allocation etc.
3	Manager	Quality	13	Quality checks for the products.
4	Manager	Maintenance	12	Spare part management, predictive, preventive and breakdown maintenance.
5	Deputy Manager	Production	10	Monitoring of production processes and adjusts schedules as suitable.
6	Director	Production	25	Pattern making, welding, gas cutting and operation of machines & furnaces.

7	Assistant Manager	Maintenance	9	To attend and resolve breakdowns in minimum possible time.
8	Assistant Manager	Production	7	Making daily production schedules and its monitoring for execution.

Step2. Identify best (B) criterion and worst (W) criterion.

Each of the eight managers in this step were asked to identify best and worst main criteria and sub-criteria according to their experience, preferences and knowledge and in relation to their organizations and industry. This can be seen in Table A (See Appendix).

Step 3. Using a scale of 1 to 9, each of the eight managers were asked to first conduct a pairwise comparison of the best main criterion over the other main criteria, and then, the best sub-criterion over the other sub-criteria. These can be seen in rows 1 & 2 of Table B and in rows 1 & 2 of Tables C, D & E respectively (See Appendix).

Step 4. Using a scale of 1 to 9, each of the eight managers were again asked to first conduct a pairwise comparison of the other main criteria over the worst criterion, and then, the other sub-criteria over the worst sub-criterion. These can be seen in rows 3 - 6 of Table B and rows 3-12 of Table C, rows 3-7 of Table D & rows 3-8 of Table E respectively (See Appendix).

Step 5. The optimal weights of the main and sub-criteria are computed

In this step, the main and sub-criteria optimal weights are computed using Equation 3. The weights of the main and sub-criteria for each of the eight experts were computed and simply averaged (See Table E, at Appendix). The importance weights of the manufacturing performance evaluation main and sub-criteria are shown in Table 3.

Table 3: Main and sub-criteria Importance Weights

Main (i)	**Wts (α i)**	**Sub-criteria (j)**	**Wts (β ij)**
Operational (O)	0.562	O_1	0.119
		O_2	0.143
		O_3	0.192
		O_4	0.099
		O_5	0.101
		O_6	0.074
		O_7	0.082
		O_8	0.101

		O_9	0.089
Social (Stakeholder's) (S)	0.213	S_1	0.136
		S_2	0.393
		S_3	0.278
		S_4	0.192
Management (M)	0.225	M_1	0.237
		M_2	0.119
		M_3	0.323
		M_4	0.215
		M_5	0.106

Stage 4: Development of Manufacturing Performance Evaluation Index

After obtaining the importance weights for both the main criteria (i) and sub- criteria (j) of manufacturing performance evaluation using BWM, the proposed model is mathematically formulated following equation 5. The proposed manufacturing performance evaluation index (MPEI) model is as shown in equation 5.

$$\begin{aligned} MPEI = {} & 0.562\,(0.119\,X_{11} + 0.143\,X_{12} + 0.192\,X_{13} + 0.099\,X_{14} + 0.101\,X_{15} + 0.074\,X_{16} + 0.082\,X_{17} + 0.101\,X_{18} + 0.089\,X_{19}) \\ & + 0.213\,(0.136\,X_{21} + 0.393\,X_{22} + 0.278\,X_{23} + 0.192\,X_{24}) \\ & + 0.225\,(0.237\,X_{31} + 0.119\,X_{32} + 0.323\,X_{33} + 0.215\,X_{34}\ 0.106\,X_{35} \end{aligned} \quad (5)$$

Stage 5: Implementation of the Manufacturing Performance Evaluation Index

In this stage, the proposed manufacturing performance evaluation index model is implemented in the case company using empirical data. The company provided data for the last twelve (12) months. Table G (See Appendix) shows the data provided by the case company that was used for the implementation of the proposed manufacturing performance evaluation index system.

The case company’s manufacturing performance is calculated using equation 5 and Table G. Figure 2 shows manufacturing performance of the case company for twelve (12) months. Similarly figure 3 shows the case company performance for twelve (12) months in terms of considered broad (main) categories including operational, social, and management.

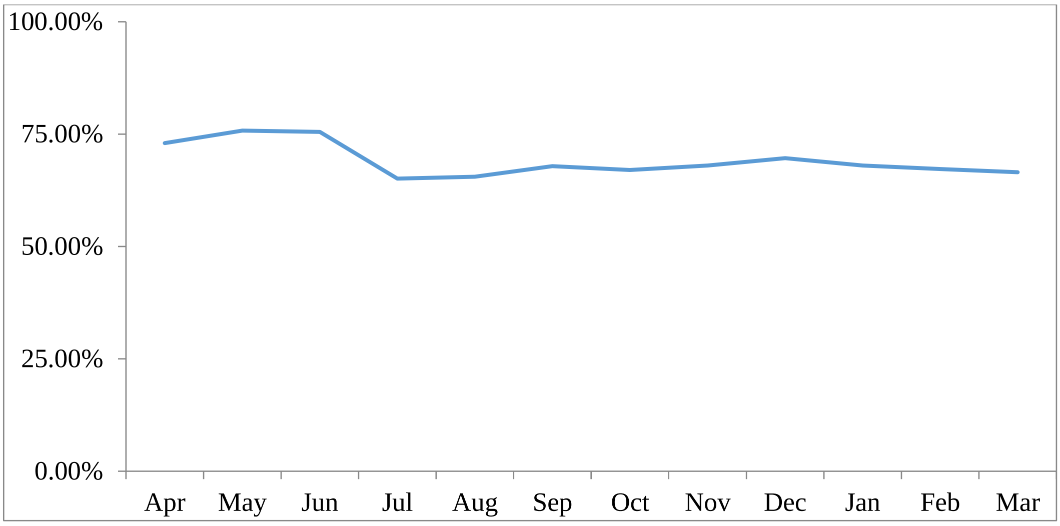

Figure 2: Manufacturing Performance Evaluation of a Case Company

Figure 3: Manufacturing Performance in terms of Considered Categories

4.2 Results discussion and implications

This section is decomposed in two different sub-sections. The first sub-section discusses the results obtained from study whiles the second sub-section discusses the academic, managerial and country insights and implications cultivated from the study.

4.2.1 Discussion of results and validation

Due to unpredictable global competition and high-frequency market changes, to stay competitive, manufacturers must possess some new and advanced manufacturing systems with re-configurability in order to meet all these changes rapidly and cost-effectively (Chao, Aiping and Liyun, 2007). These manufacturing systems should adjust their production functionality and capacity in time by changing system configurations; hence, it is very important to analyze the impact of different criteria on manufacturing system performance. Decision makers and manufacturing managers' often-received manufacturing performance information from varies criteria (Berrah, Mauris and Montmain, 2008). Often this scattered information is neither integrated nor sufficient to provide guidelines for improvement. A study (Qalati et al., 2020) shows the impact of technology, organization, social and environment as important factors in the performance of small and medium-sized enterprises. Similar to this the present study has categorized these criteria into three broad categories such as organizational (O), Social Stakeholders (S) and Management (M). These categories can represent the broader prospect of the organization performance.

All the relevant criteria can be mapped within these three categories to judge the performance of manufacturing organization. Related to criteria O1, O2, O3, O4, O5, O6, O7, O8, O9, M2, M4 and M5 are taken by compiling the researches (Hon (2005); ElMaraghy et al. (2009); Tunälv (1992); Mattias (2007); Rachna and Peter (2003); Wheelwright (1984); Gerwin (1987); and Khan and Zaidi (2012)) whereas criteria S1, S2, S3 and S4 are suggested by experts to explore the dimensions of category Social Stakeholders. The criteria M1 and M3 are also suggested by experts as to define category management more clearly and to cover all the aspects of this category. In the Indian manufacturing context, an attempt was made to establish the interactions among these categories. The calculation of categories and criteria weights are being calculated by BWM technique as it involves less pairwise comparisons as compared to other MCDM techniques and produces more consistent results due to the involvement of less pairwise comparisons. The consistent results and need of less pairwise comparisons inspire practitioners and decision makers to evaluate the performance of manufacturing firm.

From Table 3, the obtained weights for the categories (main) has the following order O > M> S. Thus, the category Organizational (O) is ranked first with a weight of 0.562, followed by Management (M) category with a weight of 0.225 and then, the third ranked is the Social (stakeholder) Category with a weight of 0.213. When considering the individual sub-criteria under each of the main (category), the following order is observed, O3 > O2 > O1 > O5 & O8 > O4 > O9 > O7 >O6 having weights of 0.192, 0.143, 0.119, 0.101, 0.101, 0.099, 0.089, 0.082

and 0.074 respectively. Flexibility (O3) got highest score represents a positive relation between a superior performance in flexibility capabilities and firm performance (Sánchez and Pérez, 2005). Production rate (O2) and Productivity (O1) got the scores as showing the importance of second and third place as Enhancement of productivity in the field of manufacturing production is of very great importance to an organization's ability to compete and make profits over time (Irshad Ali et al., 2011). Machine downtime (O5) and Quality (O8) have scores that shows equal importance. Reduction of machine downtime has a positive effect in improving productivity in manufacturing industry (Nwanya, Udofia and Ajayi, 2017). Quality management in manufacturing industry is important in order to gain global competitiveness (Lee and Zhou, 2000). Production capacity (O4) scores at fifth position as higher production capacity results in increased productivity (Büchi, Cugno and Castagnoli, 2020). Raw material quality (O9) scores at sixth will determine quality of the production in the manufacturing industry. Cost (O7) got scores at seventh position, as positive relationship exists between cost management practices and firm is performance in the manufacturing organization (Oluwagbemiga, Olugbenga and Zaccheaus, 2014). Machine reliability (O6) plays an important role in the performance improvement (Das, Lashkari and Sengupta, 2007), scores at eighth position in the present study.

The criteria under management category can be represented by following order M3 > M1 > M4 > M2 > M1 having weights 0.323, 0.237, 0.215, 0.119, and 0.106 respectively. The criteria defined by experts under the category social stakeholder can be arranged as S2 > S3 > S4 > S1 on the basis on obtained weights i.e. 0.393, 0.278, 0.192 and 0.136 respectively. These category (main) and sub-criteria weights are finally used to generate a manufacturing performance evaluation index (MPEI) at stage 4 for proposed model. This MPEI index can be applied to any manufacturing organizations to evaluate their performance. We applied the MPEI to the Indian manufacturing company to evaluate its overall manufacturing performance.

Figure 3 represent the manufacturing performance in terms of considered categories for twelve (12) months starts from April to March. It shows a complete picture of a financial year for an organization. The obtained performance of this firm varies differently under different category. Figure 3 shows each month performance of the case company in terms of social, operational, and management. From the Figure 3, it can be found that, the operational performance of the organization is very consistent and range between 60% to 70% throughout the year. Management performance can be seen high in percentage in the first two quarter of the financial year ranging from 70% to 80% whereas a slight decrease in the management performance is observed in the 3rd and 4th quarter ranging from 60% to 70%. The social stakeholder performance has a peak in first quarter ranging from 80% to 100% as at start of financial year and continuous communication with stakeholders. This shows that the social performance evaluation is essential and has positive financial performance impact (Gali et al., 2020).

In the last quarter, there is decrease in the social performance ranging from 40 % to 60 %. It is noticed that, for the first three months, social performance was acceptable, based on the considered case company benchmark, which is >, 80% that they set to monitoring their overall performance. However, the average of the first three month of operational performance was below 65%. This is because, the case company current strategy due to pressure from different stakeholders, focused more on their social and management categories, which turned out to be compromising operational performance. Therefore, once they started to realize in the fourth month, their operational performance started to improve from the fifth month onwards and reached maximum performance in the ninth month. This shows that the case company needs to focus on each aspect and categories of their manufacturing operations to remain competitive and achieve adequate performance in each category (da Silva *et al*., 2020).

It is noticed that once the case company achieved adequate operational and management categories, they suffered in achieving adequate social performance. Therefore, it is recommended that, the case company pay more attention to social aspects when considering management and operational aspects. This will help them to avoid situation similar the occurred in the fifth month, which recorded the lowest social performance and, one of the highest management performances. This also reflects the relationship between two categories. Similarly, the lowest operational performance is recorded in the first month and the highest social performance recorded in the same month. This shows a correlation between operational and social performance that need to be considered in their strategic decision-making (Khan *et al.*, 2020).

4.2.2 Academic, managerial and country implications

The outcome from the study do have some implications for academic and practice. These are discussed in the rest of the section.

The outcome from the study do have some implications for academic and practice. These are discussed in the rest of the section.

From managerial perspective, this study offers two unique benefits to managers. First, it provides manufacturing industry managers with a performance evaluation index system based on BWM that can be easily replicate for any manufacturing organization after minor adjustments. Second, it will help manufacturing organization managers to include main criteria and sub- criteria that are relevant to them to implement or modified manufacturing performance evaluation index system. The generated MPEI produces consistent results as it is based on BWM technique that require lesser pairwise comparisons. Due to advancement in technology that allows organizations and decision makers to store and organize real time data for efficient performance evaluation and decision making (Khan *et al*., 2019), proposed MPEI is in line with this new trend. Therefore, managers and decision makers can use this proposed evaluation system index in evaluating real time performance. This will also allow managers to take corrective action that will help them to improve overall organization manufacturing performance.

Some country and manufacturing sector specific implications do exits. The India manufacturing industry may face more social pressures than the operational and management pressures. According to Malek and Desai (2019), the decision making in manufacturing organizations considering the triple bottom line (economic, environmental and social) dimensions is very complex when prioritizing and selection. Thus, operational and management dimensions may have been developed and that social dimension is yet or less developed and may need more attention for the manufacturing organizations to survive in the global competition. Indian manufacturing companies may not have the requisite resources to help them adopt and implement all the elements of the framework for performance improvement simultaneously and may require selecting among these elements. Therefore, maximizing the performance outcome in such a resources-constraints situation is aim of most industries, thus, this modelling effort and findings can aid in setting foundation towards this goal.

Thus, operational (O), Social Stakeholders (S) and Management (M) criteria in manufacturing industry has a greater impact on its performance. This paper provides guidance to the industrial manager for the vital indicators under the categories operation, social stakeholders and management. It also helps in decision making through ranking of these indicators by using best worst method. Ranking is provided based upon the importance of these indicators by assigning weights to them. In order to calculate the performance evaluation of manufacturing organization, this study builds a combined performance evaluation model based on BWM that can be utilized by similar organization in the evaluation of the its performance.

5. Conclusion and Future Research Direction

5.1 Summary

Manufacturing operations plays a very important role in the success of any organization, particularly in the emerging economies such as India. Decision makers and manufacturing managers' often-received manufacturing performance information from varies criteria. Often this scattered information is neither integrated nor enough to provide guidelines for improvement. With the increasing unpredictable and unprecedented global competition coupled with the high frequency of market turbulences, to stay highly competitive, manufacturing organizations are required to adjust their production functions and capacity in time via changing their system configurations. Therefore, it is extremely imperative to evaluate the effect of different criteria on manufacturing system performance. Thus, it is imperative for manufacturing organizations to evaluate their performance in an effective and efficient way and pursue new and advanced manufacturing systems with re-configurability to enable them to meet all these changes in rapid and cost-effectively manner. In addition to that, this will also allow them to remain competitive and take corrective actions based on real time data collection and performance evaluation. This study proposed a comprehensive performance evaluation index that can help managers and decision makers to evaluate their organizational performance effectively and efficiently. The implementation of the proposed index system occurred in an Indian manufacturing company, which shows its applicability and effectiveness. Our proposed manufacturing performance index consists of three main category, operational, social stakeholders, and management and eighteen sub-criteria. These categories can represent the broader prospect of the organization performance. Related to these categories, 'organizational'; and 'management' were identified from existing literature whereas 'social stakeholder' was suggested by experts as its important dimension for performance evaluation related to manufacturing firms. BWM, one of the most efficient MCDM method was used to aid in developing this manufacturing performance evaluation index system.

5.2 Limitations and future research directions

This study is subject to some limitations and this provides an opportunity to further extend our proposed manufacturing performance evaluation index. In this study, we have used BWM in developing the index, future studies could use other MCDM methods in calculating the importance weight of category (main) and sub-criteria. In addition, future studies could consider both inter-relationships and intra-relationships among the category (main) and sub-criteria when determining the weights of the category (main) and sub-criteria and perform sensitivity analysis. The proposed evaluation index is implanted in a single case company, future studies can consider implementing it in different manufacturing companies to get generalized application.

References

Abadi, F., Sahebi, I., Arab, A., Alavi, A. and Karachi, H. (2018), "Application of best-worst method in evaluation of medical tourism development strategy", *Decision Science Letters*, Vol 7 No 1, pp. 77-86. doi:10.5267/j.dsl.2017.4.002

Adjei-Bamfo, P., Bempong, B., Osei, J. and Kusi-Sarpong, S. (2019), "Green candidate selection for organizational environmental management", *International Journal of Manpower*. doi: 10.1108/IJM-10-2019-0480 (Early Cite).

Agami, N., Saleh, M. and Rasmy, M. (2014), "An Innovative Fuzzy Logic Based Approach for Supply Chain Performance Management", *IEEE Systems Journal*, Vol. 8 No. 2, pp. 336-342. doi: 10.1109/JSYST.2012.2219913.

Ahmad, W. N. K. W., Rezaei, J., Sadaghiani, S. and Tavasszy, L. A. (2017), "Evaluation of the external forces affecting the sustainability of oil and gas supply chain using Best Worst Method", *Journal of Cleaner Production*, Vol. 153, pp. 242–252. doi: 10.1016/J.JCLEPRO.2017.03.166.

Alimohammadlou, M. and Bonyani, A. (2018), "A comparative analysis of dynamic and cross-sectional approaches for financial performance analysis", *American Journal of Finance and Accounting*, Vol. 5 No. 3, p. 253-275. doi:10.1504/AJFA.2018.093037.

Amrina, E., & Yusof, S. M. (2013, June). An AHP based-model for sustainable manufacturing performance evaluation in automotive industry. In Proceedings of the 12th International Symposium on the Analytic Hierarchy Process for Multi-criteria Decision Making, Kuala Lumpur, Malaysia (pp. 23-26).

Angerhofer, B. J. and Angelides, M. C. (2006), "A model and a performance measurement system for collaborative supply chains", *Decision Support Systems*, Vol. 42 No. 1, pp. 283-301. doi:10.1016/j.dss.2004.12.005.

Asadabadi, M. R., Chang, E., Zwikael, O., Saberi, M. and Sharpe, K. (2020), "Hidden fuzzy information: Requirement specification and measurement of project provider performance using the best worst method", *Fuzzy Sets and Systems*, Vol. 383, pp. 127-145. doi: 10.1016/j.fss.2019.06.017.

Ataei, Y., Mahmoudi, A., Feylizadeh, M. R., & Li, D. F. (2020). Ordinal priority approach (OPA) in multiple attribute decision-making. Applied Soft Computing, Vol. 86, pp. 105893. doi: 10.1016/j.asoc.2019.105893.

Badri Ahmadi, H., Kusi-Sarpong, S. and Rezaei, J. (2017), "Assessing the social sustainability of supply chains using Best Worst Method", *Resources, Conservation and Recycling*, Vol.126, pp. 99-106. doi:10.1016/j.resconrec.2017.07.020.

Bai, C., Kusi-Sarpong, S., Badri Ahmadi, H. and Sarkis, J. (2019), "Social sustainable supplier evaluation and selection: a group decision-support approach", *International Journal of Production Research*, Vol. 57 No. 22, pp. 7046-7067. doi:10.1080/00207543.2019.1574042.

Bai, C., Sarkis, J., Wei, X. and Koh, L. (2012), "Evaluating ecological sustainable performance measures for supply chain management", *Supply Chain Management: An International Journal*, Vol. 17 No. 1, pp. 78-92. doi:10.1108/13598541211212221.

Beamon, B. M. (1999), "Measuring supply chain performance", *International Journal of Operations & Production Management*, Vol. 19 No.3, pp. 275-292. doi:10.1108/01443579910249714.

Berrah, L., Mauris, G., & Montmain, J. (2008). Monitoring the improvement of an overall industrial performance based on a Choquet integral aggregation. *Omega*, Vol. 36, No. 3, pp. 340-351. doi: 10.1016/j.omega.2006.02.009.

Bhagwat, R. and Sharma, M. K. (2009), "An application of the integrated AHP-PGP model for performance measurement of supply chain management", *Production Planning & Control*, Vol. 20 No. 8, pp. 678-690. doi:10.1080/09537280903069897.

Bhattacharya, A., Mohapatra, P., Kumar, V., Dey, P. K., Brady, M., Tiwari, M. K. and Nudurupati, S. S. (2014), "Green supply chain performance measurement using fuzzy ANP-based balanced scorecard: a collaborative decision-making approach", *Production Planning & Control*, Vol. 25 No. 8, pp. 698-714. doi:10.1080/09537287.2013.798088.

Brignall, S. and Modell, S. (2000), "An institutional perspective on performance measurement and management in the 'new public sector'", *Management Accounting Research*, Vol. 11 No. 3, pp. 281-306. doi: https://doi.org/10.1006/mare.2000.0136.

Bourne, M., Neely, A., Mills, J. and Platts, K. (2003), "Implementing performance measurement systems: a literature review", *International Journal of Business Performance Management*, Vol. 5 No. 1, pp. 1-24. doi:10.1504/ijbpm.2003.002097.

Büchi, G., Cugno, M., & Castagnoli, R. (2020). Smart factory performance and Industry 4.0. *Technological Forecasting and Social Change*, Vol. 150, pp. 119790. doi.org/10.1016/j.techfore.2019.119790

Büyüközkan, G., & Güleryüz, S. (2016). An integrated DEMATEL-ANP approach for renewable energy resources selection in Turkey. *International journal of production economics*, Vol. 182, pp. 435-448. doi.org/10.1016/j.ijpe.2016.09.015.

Cai, J., Liu, X., Xiao, Z. and Liu, J. (2009), "Improving supply chain performance management: A systematic approach to analyzing iterative KPI accomplishment", *Decision Support Systems*, Vol. 46 No. 2, pp. 512-521. doi.org/10.1016/j.dss.2008.09.004

Carlsson-Wall, M., Kraus, K. and Messner, M. (2016), "Performance measurement systems and the enactment of different institutional logics: Insights from a football organization", *Management Accounting Research*, Vol. 32, pp. 45-61. doi.org/10.1016/j.mar.2016.01.006.

Chan, F. T. S. and Qi, H. J. (2003), “An innovative performance measurement method for supply chain management”, *Supply Chain Management: An International Journal*, Vol. 8 No. 3, pp. 209-223. doi:10.1108/13598540310484618.

Chan, F. T. S. (2003), “Performance Measurement in a Supply Chain”, *International Journal of Advanced Manufacturing Technology*, Vol. 21 No. 7, pp. 534-548. doi:10.1007/s001700300063

Chithambaranathan, P., Subramanian, N., Gunasekaran, A. and Palaniappan, P. K. (2015), “Service supply chain environmental performance evaluation using grey based hybrid MCDM approach”, *International Journal of Production Economics*, Vol. 166, pp. 163-176. doi.org/10.1016/j.ijpe.2015.01.002.

Coronado Mondragon, A. E., Lalwani, C. and Coronado Mondragon, C. E. (2011), “Measures for auditing performance and integration in closed-loop supply chains”, *Supply Chain Management: An International Journal*, Vol. 16 No. 1, pp. 43-56. doi:10.1108/13598541111103494.

Cuthbertson, R. and Piotrowicz, W. (2011), “Performance measurement systems in supply chains: A framework for contextual analysis”, *International Journal of Productivity and Performance Management*, Vol. 60 No. 6, pp. 583-602. doi:10.1108/17410401111150760.

da Silva, P. C., de Oliveira Neto, G. C., Correia, J. M. F. and Tucci, H. N. P. (2020), “Evaluation of economic, environmental and operational performance of the adoption of cleaner production: Survey in large textile industries”, *Journal of Cleaner Production*, Vol. 278, 123855. doi.org/10.1016/j.jclepro.2020.123855.

Das, K., Lashkari, R. S. and Sengupta, S. (2007) ‘Machine reliability and preventive maintenance planning for cellular manufacturing systems’, European Journal of Operational Research. North-Holland, Vol. 183, No. 1, pp. 162–180. doi: 10.1016/j.ejor.2006.09.079

Dubey, R., Gunasekaran, A., Childe, S. J., Papadopoulos, T., Hazen, B., Giannakis, M. and Roubaud, D. (2017), “Examining the effect of external pressures and organizational culture on shaping performance measurement systems (PMS) for sustainability benchmarking: Some empirical findings”, *International Journal of Production Economics*, Vol. 193, pp. 63-76. doi.org/10.1016/j.ijpe.2017.06.029.

Dweekat, A. J., Hwang, G. and Park, J. (2017), “A supply chain performance measurement approach using the internet of things: Toward more practical SCPMS”, *Industrial Management & Data Systems*, Vol. 117 No. 2, pp. 267-286. doi:10.1108/IMDS-03-2016-0096.

Dweiri, F. and Khan, S. A. (2012), “Development of a universal supply chain management performance index”, *International Journal of Business Performance and Supply Chain Modelling*, Vol. 4 No. 3-4, pp. 232-245. doi.org/10.1504/IJBPSCM.2012.050387.

Dwivedi, R., Prasad, K., Mandal, N., Singh, S., Vardhan, M., & Pamucar, D. (2021). Performance evaluation of an insurance company using an integrated Balanced Scorecard (BSC) and Best-Worst Method (BWM). *Decision Making: Applications in Management and Engineering*, Vol. 4 No. 1, pp.33-50. doi.org/10.31181/dmame2104033d.

ElMaraghy, H., Azab, A., Schuh, G., and Pulz, C. (2009), “Managing variations in products, processes and manufacturing systems” *CIRP annals*, Vol. 58 No. 1, pp. 441–446. doi.org/10.1016/j.cirp.2009.04.001.

Estampe, D., Lamouri, S., Paris, J.-L. and Brahim-Djelloul, S. (2013), “A framework for analysing supply chain performance evaluation models”, *International Journal of Production Economics*, Vol. 142 No. 2, pp. 247-258. doi.org/10.1016/j.ijpe.2010.11.024.

Ferreira, L. M. D. F., Silva, C. and Azevedo, S. G. (2016), An environmental balanced scorecard for supply chain performance measurement (Env_BSC_4_SCPM)”, *Benchmarking: An International Journal*, Vol. 23 No. 6, pp. 1398-1422. doi:10.1108/BIJ-08-2013-0087.

Gali, N., Niemand, T., Shaw, E., Hughes, M., Kraus, S. and Brem, A. (2020), “Social entrepreneurship orientation and company success: The mediating role of social performance”, *Technological Forecasting and Social Change*, Vol. 160, 120230. doi.org/10.1016/j.techfore.2020.120230.

Ganga, G. M. D. and Carpinetti, L. C. R. (2011), “A fuzzy logic approach to supply chain performance management”, *International Journal of Production Economics*, Vol. 134 No. 1, pp. 177-187. doi.org/10.1016/j.ijpe.2011.06.011.

Garg, C. P. and Sharma, A. (2018), “Sustainable outsourcing partner selection and evaluation using an integrated BWM–VIKOR framework”, *Environment, Development and Sustainability*, Vol. 22, pp. 1529–1557. doi.org/10.1007/s10668-018-0261-5.

Gerwin, D. (1987), “An agenda of research on the flexibility of manufacturing processes”, *International Journal of Operations & Production Management*, Vol. 7 No. 1, pp. 38-49. doi.org/10.1108/eb054784.

Ghaffari, S., Arab, A., Nafari, J. and Manteghi, M. (2017), “Investigation and evaluation of key success factors in technological innovation development based on BWM”, *Decision Science Letters*, Vol. 6 No. 3, pp. 295–306. doi: 10.5267/j.dsl.2016.12.001.

Ghalayini, A. M., Noble, J. S. and Crowe, T. J. (1997), “An integrated dynamic performance measurement system”, *International Journal of Production Economics*, Vol. 48 No. 3, pp. 207–225. doi.org/10.1016/S0925-5273(96)00093-X.

Gunasekaran, A. and 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*, Vol. 45 No. 12, pp. 2819-2840. doi:10.1080/00207540600806513.

Guo, S. and Zhao, H. (2017), “Fuzzy best-worst multi-criteria decision-making method and its applications”, *Knowledge-Based Systems*, Vol. 121, pp. 23-31. doi.org/10.1016/j.knosys.2017.01.010.

Gupta, H. and Barua, M. K. (2017), “Supplier selection among SMEs on the basis of their green innovation ability using BWM and fuzzy TOPSIS”, *Journal of Cleaner Production*, Vol. 152, pp. 242-258. doi.org/10.1016/j.jclepro.2017.03.125.

Gupta, H. (2018), “Assessing organizations performance on the basis of GHRM practices using BWM and Fuzzy TOPSIS”, *Journal of Environmental Management*, Vol. 226, pp. 201–216. doi: 10.1016/J.JENVMAN.2018.08.005.

Gupta, H., Kusi-Sarpong, S. and Rezaei, J. (2020), “Barriers and overcoming strategies to supply chain sustainability innovation”. *Resources Conservation and Recycling*. doi.org/10.1016/j.resconrec.2020.104819. (Early Cite).

Gupta, H., Kumar, S., Kusi-Sarpong, S., Jabbour, C. J. C., & Agyemang, M. (2020). Enablers to supply chain performance on the basis of digitization technologies. *Industrial Management & Data Systems*. doi.org/10.1108/IMDS-07-2020-0421. (Early Cite).

Hasan, S. M., Khan, S. A. and Shah, S. (2017), "Supply chain performance improvement within collaborative product development environment", *International Journal of Business Performance and Supply Chain Modelling*, Vol. 9 No. 4, pp. 261-279. doi.org/10.1504/IJBPSCM.2017.091316.

Hassini, E., Surti, C. and Searcy, C. (2012), "A literature review and a case study of sustainable supply chains with a focus on metrics", *International Journal of Production Economics*, Vol. 140 No. 1, pp. 69-82. doi.org/10.1016/j.ijpe.2012.01.042.

Hofmann, E. and Locker, A. (2009), "Value-based performance measurement in supply chains: a case study from the packaging industry", *Production Planning & Control*, Vol. 20 No. 1, pp. 68-81. doi:10.1080/09537280802685272.

Holmberg, S. (2000), "A systems perspective on supply chain measurements", *International Journal of Physical Distribution & Logistics Management*, Vol. 30 No. 10, pp. 847-868. doi:10.1108/09600030010351246.

Hon, KKB. (2005), "Performance and evaluation of manufacturing systems", *CIRP Annals-Manufacturing Technology*, Vol. 54 No. 2, pp. 139–154. doi.org/10.1016/S0007-8506(07)60023-7.

Irshad Ali, S. et al. (2011) 'Evaluation of performance in manufacturing organization through productivity and quality', *African Journal of Business Management. Academic Journals*, Vol. 5, No. 6, pp. 2211–2219. doi: 10.5897/AJBM10.720.

Jääskeläinen, A. and Thitz, O. (2018), "Prerequisites for performance measurement supporting purchaser-supplier collaboration", *Benchmarking: An International Journal*, Vol. 25 No. 1, pp. 120-137. doi:10.1108/BIJ-08-2016-0121.

Jayaram, J., Dixit, M. and Motwani, J. (2014), Supply chain management capability of small and medium sized family businesses in India: A multiple case study approach", *International Journal of Production Economics*, Vol. 147, pp. 472-485. doi.org/10.1016/j.ijpe.2013.08.016.

Jain, S., Triantis, K., and Liu, S. (2011), "Manufacturing performance measurement and target setting: A data envelopment analysis approach", *European Journal of Operational Research*, Vol. 214 No. 3, pp. 616–626. doi.org/10.1016/j.ejor.2011.05.028

Jakhar, S. K. and Barua, M. K. (2014), "An integrated model of supply chain performance evaluation and decision-making using structural equation modelling and fuzzy AHP", *Production Planning & Control*, Vol. 25 No. 11, pp. 938-957. doi:10.1080/09537287.2013.782616.

Kamble, S. S., Gunasekaran, A., Ghadge, A. and Raut, R. (2020), "A performance measurement system for industry 4.0 enabled smart manufacturing system in SMMEs-A review and empirical investigation", *International Journal of Production Economics*, Vol. 229, 107853. doi.org/10.1016/j.ijpe.2020.107853 (Early Cite).

Keršuliene, V., Zavadskas, E. K., & Turskis, Z. (2010), "Selection of rational dispute resolution method by applying new step-wise weight assessment ratio analysis (SWARA)", *Journal of business economics and management*, Vol. 11, No. 2, pp. 243-258. doi/abs/10.3846/jbem.2010.12

Khan, S. A., Chaabane, A. and Dweiri, F. (2019), "A knowledge-based system for overall supply chain performance evaluation: a multi-criteria decision making approach", *Supply Chain Management: An International Journal*, Vol. 24 No. 3, pp. 377-396. doi.org/10.1108/SCM-06-2017-0197

Khan, S. A., Mubarik, M. S., Kusi-Sarpong, S., Zaman, S. I. and Kazmi, S. H. A. (2020), "Social sustainable supply chains in the food industry: A perspective of an emerging economy", *Corporate Social Responsibility and Environmental Management*, Vol. 28 No. 1, pp. 404-418. doi.org/10.1002/csr.2057

Khan, S. A., Kusi-Sarpong, S., Arhin, F. K. and Kusi-Sarpong, H. (2018), "Supplier sustainability performance evaluation and selection: A framework and methodology", *Journal of cleaner production*, Vol. 205, pp. 964-979. https://doi.org/10.1016/j.jclepro.2018.09.144

Khan, S. A., Dweiri, F. and Chaabane, A. (2016, December). Fuzzy-AHP approach for warehouse performance measurement. In 2016 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM) (pp. 871-875). IEEE.

Khan, S.A, and Zaidi, S.A, (2012), "Ranking of Manufacturing Systems Criteria", *International Journal of Engineering Science & Technology* (IJEST), Vol.4 No. 6, pp. 2936-2941.

Kochhar, A. and Eguia, F. (1998), "A Quality Function Deployment Approach to Performance Measurement and Benchmarking in Manufacturing Control Systems", *IFAC Proceedings* Volumes, Vol. 31 No. 15, pp. 815-820. doi.org/10.1016/S1474-6670(17)40653-7

Kumar, A., Mukherjee, K. and Adlakha, A. (2015), "Dynamic performance assessment of a supply chain process: A case from pharmaceutical supply chain in India", *Business Process Management Journal*, Vol. 21 No. 4, pp. 743-770. doi:10.1108/BPMJ-09-2014-0086

Kusi-Sarpong, S., Gupta, H. and Sarkis, J. (2019), "A supply chain sustainability innovation framework and evaluation methodology", *International Journal of Production Research*, Vol. 57 No. 7, pp.1990-2008. doi.org/10.1080/00207543.2018.1518607

Kusi-Sarpong, S., Sarkis, J., & Wang, X. (2016). Assessing green supply chain practices in the Ghanaian mining industry: A framework and evaluation. *International Journal of Production Economics*, 181, 325-341. doi.org/10.1016/j.ijpe.2016.04.002

Laihonen, H. and Pekkola, S. (2016), "Impacts of using a performance measurement system in supply chain management: a case study", *International Journal of Production Research*, Vol. 54 No. 18, pp. 5607-5617. doi:10.1080/00207543.2016.1181810.

Lee, C. Y. and Zhou, X. (2000) 'Quality management and manufacturing strategies in China', *International Journal of Quality and Reliability Management*. MCB UP Ltd, Vol. 17, No. 8, pp. 876–899. doi: 10.1108/02656710010325101.

Lima-Junior, F. R. and Carpinetti, L. C. R. (2017), "Quantitative models for supply chain performance evaluation: A literature review", *Computers & Industrial Engineering*, Vol. 113, pp. 333-346. doi.org/10.1016/j.cie.2017.09.022.

Liu, S. T. (2008), “Slacks-based efficiency measures for predicting bank performance”, *Expert Systems with Applications*, Vol. 36 No. 2, pp. 2813–2818. doi.org/10.1016/j.eswa.2008.01.032

Lin, C., Kou, G., Peng, Y., & Alsaadi, F. E. (2020). Aggregation of the nearest consistency matrices with the acceptable consensus in AHP-GDM. *Annals of Operations Research*, pp. 1-17. doi.org/10.1007/s10479-020-03572-1

Loh, T. Y., Brito, M. P., Bose, N., Xu, J., & Tenekedjiev, K. (2020). Fuzzy system dynamics risk analysis (FuSDRA) of autonomous underwater vehicle operations in the Antarctic. *Risk Analysis*, Vol. 40 No. 4, pp. 818-841. doi.org/10.1111/risa.13429

Luzzini, D., Caniato, F. and Spina, G. (2014), “Designing vendor evaluation systems: An empirical analysis”, *Journal of Purchasing and Supply Management*, Vol. 20 No. 2, pp. 113-129. doi.org/10.1016/j.pursup.2014.03.002.

Lv, C., Li, A., & Xu, L. (2007, August). The research of performance evaluation system on manufacturing system with reconfigurable configuration. In 2007 International Conference on Mechatronics and Automation (pp. 1005-1010). IEEE.

Maestrini, V., Luzzini, D., Caniato, F., Maccarrone, P. and Ronchi, S. (2018), “Measuring supply chain performance: a lifecycle framework and a case study”, *International Journal of Operations & Production Management*, Vol. 38 No. 4, pp. 934-956. doi:10.1108/IJOPM-07-2015-0455

Maestrini, V., Luzzini, D., Maccarrone, P. and Caniato, F. (2017), Supply chain performance measurement systems: A systematic review and research agenda”, *International Journal of Production Economics*, Vol. 183, pp. 299-315. doi.org/10.1016/j.ijpe.2016.11.005.

Mahmoudi, R., Shetab-Boushehri, S. N., Hejazi, S. R. and Emrouznejad, A. (2019), “Determining the relative importance of sustainability evaluation criteria of urban transportation network”, *Sustainable Cities and Society*, Vol. 47, pp. 101493. doi: 10.1016/J.SCS.2019.101493.

Malek, J. and Desai, T. N. (2019), “Prioritization of sustainable manufacturing barriers using Best Worst Method”, *Journal of Cleaner Production*, Vol. 226, pp. 589–600. doi: 10.1016/J.JCLEPRO.2019.04.056.

Marulanda-Grisales, N. and Figueroa-Duarte, O. D., (2021), “Classifying and studying environmental performance of manufacturing organizations evidence from Colombia”, *Journal of Cleaner Production*, Vol. 279, 123845 doi.org/10.1016/j.jclepro.2020.123845.

Mattias, H. (2007). Manufacturing strategy, capabilities and performance. PhD thesis, Institutionen för ekonomisk och industriell utveckling, Linköpings universitet.

Mi, X., Tang, M., Liao, H., Shen, W., & Lev, B. (2019). The state-of-the-art survey on integrations and applications of the best worst method in decision making: Why, what, what for and what's next? *Omega*, Vol. 87, pp. 205-225. doi.org/10.1016/j.omega.2019.01.009

Morgan, C. and Dewhurst, A. (2007), “Using SPC to measure a national supermarket chain's suppliers' performance”, *International Journal of Operations & Production Management*, Vol. 27 No. 8, pp. 874-900. doi:10.1108/01443570710763813.

Muravev, D., & Mijic, N. (2020). A Novel Integrated Provider Selection Multicriteria Model: The BWM-MABAC Model. *Decision Making: Applications in Management and Engineering*, Vol. 3 No. 1, pp. 60-78. doi.org/10.31181/dmame2003078m

Neely, A., Adams, C. and Crowe, P. (2001), "The performance prism in practice" *Measuring Business Excellence*, Vol. 5 No. 2, pp. 6-13. doi:10.1108/13683040110385142

Neely, A., Richards, H., Mills, J., Platts, K., Bourne, M., (1997), "Designing performance measures: a structured approach", *International Journal of Operations & Production Management*, Vol. 17 No. 11, pp. 1131–1152. doi.org/10.1108/01443579710177888

Niaki, M. K., Torabi, S. A. and Nonino, F. (2019), "Why manufacturers adopt additive manufacturing technologies: The role of sustainability", *Journal of Cleaner Production*, Vol. 222, pp. 381–392. doi: 10.1016/J.JCLEPRO.2019.03.019.

Nie, R. X., Tian, Z. P., Wang, J. Q., Zhang, H. Y. and Wang, T. L. (2018), "Water security sustainability evaluation: Applying a multistage decision support framework in industrial region", *Journal of Cleaner Production*, Vol. 196, pp. 1681–1704. doi: 10.1016/J.JCLEPRO.2018.06.144.

Nwanya, S. C., Udofia, J. I. and Ajayi, O. O. (2017) 'Optimization of machine downtime in the plastic manufacturing', Cogent Engineering. Cogent OA, Vol. 4, No. 1. doi: 10.1080/23311916.2017.1335444.

Orji, I. J., Kusi-Sarpong, S., Huang, S., & Vazquez-Brust, D. (2020). Evaluating the factors that influence blockchain adoption in the freight logistics industry. T*ransportation Research Part E: Logistics and Transportation Review*, Vol. 141, pp. 102025. doi.org/10.1016/j.tre.2020.102025.

Okoshi, C. Y., de Lima, E. P. and Da Costa, S. E. G. (2019), "Performance cause and effect studies: Analyzing high performance manufacturing companies", *International Journal of Production Economics*, Vol. 210, pp. 27-41. doi.org/10.1016/j.ijpe.2019.01.003

Olugu, E. U., Wong, K. Y. and Shaharoun, A. M. (2011), "Development of key performance measures for the automobile green supply chain", *Resources, Conservation and Recycling*, Vol. 55 No. 6, pp. 567-579. doi.org/10.1016/j.resconrec.2010.06.003.

Oluwagbemiga, O. E., Olugbenga, O. M. and Zaccheaus, S. A. (2014) 'Cost Management Practices and Firm's Performance of Manufacturing Organizations', International Journal of Economics and Finance. Canadian Center of Science and Education, Vol. 6, No. 6. doi: 10.5539/ijef.v6n6p234.

Önüt, S., Kara, S. S. and Isik, E. (2008), "Long term supplier selection using a combined fuzzy MCDM approach: A case study for a telecommunication company", *Expert Systems with Applications*, Vol. 36 No. 2, pp. 3887–3895. doi.org/10.1016/j.eswa.2008.02.045.

Orji, I. J., Kusi-Sarpong, S., Gupta, H. and Okwu, M. (2019), "Evaluating challenges to implementing eco-innovation for freight logistics sustainability in Nigeria", *Transportation Research Part A: Policy and Practice*, Vol. 129, pp. 288-305. doi.org/10.1016/j.tra.2019.09.001.

Orji, I. J., Kusi-Sarpong, S. and Gupta, H. (2020), "The critical success factors of using social media for supply chain social sustainability in the freight logistics industry", *International Journal of Production Research*, Vol. 58 No. 5, pp. 1522-1539. doi.org/10.1080/00207543.2019.1660829.

Pamučar, D., Stević, Ž., & Sremac, S. (2018). A new model for determining weight coefficients of criteria in mcdm models: Full consistency method (FUCOM). Symmetry, 10(9), 393. doi.org/10.3390/sym10090393.

Prahinski, C. and Benton, W. C. (2004), "Supplier evaluations: communication strategies to improve supplier performance", *Journal of Operations Management*, Vol. 22 No. 1, pp. 39-62. doi.org/10.1016/j.jom.2003.12.005.

Prahinski, C. and Fan, Y. (2007), "Supplier Evaluations: The Role of Communication Quality", *Journal of Supply Chain Management*, Vol. 43 No. 3, pp. 16-28. doi:10.1111/j.1745-493X.2007.00032.x

Qalati, S. A., Li, W., Ahmed, N., Mirani, M. A., & Khan, A. (2021). Examining the factors affecting SME performance: the mediating role of social media adoption. *Sustainability*, Vol. 13, No. 1, pp.75. doi: 10.3390/su13010075.

Rachna, S. and Peter, T. W. (2003), "Lean manufacturing: context, practice bundles, and performance", *Journal of operations management*, Vol. 21 No. 2, pp. 129– 149. doi.org/10.1016/S0272-6963(02)00108-0

Raj, A. and Srivastava, S. K. (2018), "Sustainability performance assessment of an aircraft manufacturing firm", *Benchmarking: An International Jou*rnal, Vol. 25 No. 5, pp. 1500–1527. doi: 10.1108/BIJ-01-2017-0001.

Rehman, S. T., Khan, S. A., Kusi-Sarpong, S. and Hassan, S. M. (2018), "Supply chain performance measurement and improvement system: A MCDA-DMAIC methodology", *Journal of Modelling in Managemen*t, Vol. 13 No. 3, pp. 522-549. doi:10.1108/JM2-02-2018-0012

Rezaei, J. (2015), "Best-worst multi-criteria decision-making method", *Omega*, Vol. 53, pp. 49-57. doi.org/10.1016/j.omega.2014.11.009

Rezaei, J. (2016), "Best-worst multi-criteria decision-making method: Some properties and a linear model", *Omega*, Vol. 64, pp. 126-130. doi.org/10.1016/j.omega.2015.12.001

Rezaei, J., van Wulfften Palthe, L., Tavasszy, L., Wiegmans, B. and van der Laan, F. (2019), "Port performance measurement in the context of port choice: an MCDA approach", *Management Decision*, Vol. 57 No. 2, pp. 396–417. doi: 10.1108/MD-04-2018-0482.

Saaty, T.L. (1980) The Analytic Hierarchy Process, New York: McGraw Hill. International, Translated to Russian, Portuguese, and Chinese, Revised editions, Paperback (1996, 2000), Pittsburgh: RWS Publications.

Salimi, N. and Rezaei, J. (2018), "Evaluating firms' R&D performance using best worst method", *Evaluation and Program Planning*, Vol. 66, pp. 147-155. doi.org/10.1016/j.evalprogplan.2017.10.002

Salimi, N. and Rezaei, J. (2016), "Measuring efficiency of university-industry Ph.D. projects using best worst method", *Scientometrics*, Vol. 109 No. 3, pp. 1911-1938. doi:10.1007/s11192-016-2121-0

Salimi, N. (2017), "Quality assessment of scientific outputs using the BWM", *Scientometrics*, pp. 1-19. doi:10.1007/s11192-017-2284-3

Sánchez, A. M. and Pérez, M. P. (2005) 'Supply chain flexibility and firm performance: A conceptual model and empirical study in the automotive industry', *International Journal of Operations and Production Management*, Vol. 25, No. 7, pp. 681–700. doi: 10.1108/01443570510605090.

Sellitto, M. A., Pereira, G. M., Borchardt, M., da Silva, R. I. and Viegas, C. V. (2015), "A SCOR-based model for supply chain performance measurement: application in the footwear industry", *International Journal of Production Research*, Vol. 53 No. 16, pp. 4917-4926. doi:10.1080/00207543.2015.1005251

Shafiee, M., Hosseinzadeh Lotfi, F. and Saleh, H. (2014), "Supply chain performance evaluation with data envelopment analysis and balanced scorecard approach, *Applied Mathematical Modelling*, Vol. 38 No. 21, pp. 5092-5112. doi.org/10.1016/j.apm.2014.03.023

Sharif, A. M., Irani, Z. and Lloyd, D. (2007), "Information technology and performance management for build-to-order supply chains", *International Journal of Operations & Production Management*, Vol. 27 No. 11, pp. 1235-1253. doi:10.1108/01443570710830610

Sillanpää, I. (2015), "Empirical study of measuring supply chain performance", *Benchmarking: An International Journal*, Vol. 22 No. 2, pp. 290-308. doi:10.1108/BIJ-01-2013-0009

Singh, C., Singh, D. and Khamba, J. S. (2020), "Understanding the key performance parameters of green lean performance in manufacturing industries". Materials Today: Proceedings. doi.org/10.1016/j.matpr.2020.06.328 (Early Cite).

Sundtoft Hald, K. and Ellegaard, C. (2011), "Supplier evaluation processes: the shaping and reshaping of supplier performance", *International Journal of Operations & Production Management*, Vol. 31 No. 8, pp. 888-910. doi:10.1108/01443571111153085

Torbati, A. R., Torbati, A. R. and Sayadi, M. K. (2018), "A New Approach to Investigate the Performance of Insurance Branches in Iran Using Best-Worst Method and Fuzzy Inference System", *Journal of Soft Computing and Decision Support Systems*, Vol. 5 No. 4, pp. 13–18.

Tunälv, C. (1992), "Manufacturing strategy – plans and business performance", International Journal of Operations & Production Management, Vol. 12 No. 3, pp. 4 -24. doi.org/10.1108/01443579210008097

van Hoek, R. I. (1998), "Measuring the unmeasurable"- measuring and improving performance in the supply chain", *Supply Chain Management: An International Journal*, Vol. 3 No. 4, pp. 187-192. doi:10.1108/13598549810244232.

Waggoner, D. B., Neely, A. D. and Kennerley, M. P. (1999), "The forces that shape organisational performance measurement systems: An interdisciplinary review", *International Journal of Production Economics*, Vol. 60-61, pp. 53-60. doi.org/10.1016/S0925-5273(98)00201-1

Wheelwright, S.C. (1984), "Manufacturing strategy – defining the missing link", *Strategic Management Journal*, Vol. 5, pp.77-91. doi.org/10.1002/smj.4250050106

Yang, C.L., Chuang, S.P., and Huang, R.H., (2009), "Manufacturing evaluation system based on AHP/ANP approach for wafer fabricating industry", *Expert Systems with Applications*, Vol. 36, pp. 11369–11377. doi.org/10.1016/j.eswa.2009.03.023

You, P., Guo, S., Zhao, H. and Zhao, H. (2017), "Operation Performance Evaluation of Power Grid Enterprise Using a Hybrid BWM-TOPSIS Method", *Sustainability Multidisciplinary Digital Publishing Institute*, Vol. 9 No. 12, pp. 2329. doi: 10.3390/su9122329.

Yu, D., Kou, G., Xu, Z., & Shi, S. (2021). Analysis of collaboration evolution in AHP research: 1982–2018. *International Journal of Information Technology & Decision Making (IJITDM)*,Vol. 20 No. 1, pp. 7-36. doi.org/10.1142/S0219622020500406

Zhang, J., Kou, G., Peng, Y., & Zhang, Y. (2021). Estimating priorities from relative deviations in pairwise comparison matrices. *Information Sciences*, Vol. 552, pp. 310-327. doi.org/10.1016/j.ins.2020.12.008

Zhao, H., Guo, S. and Zhao, H. (2018), "Comprehensive Performance Assessment on Various Battery Energy Storage Systems", *Energies Multidisciplinary Digital Publishing Institute*, Vol. 11 No. 10, pp. 2841. doi: 10.3390/en11102841.

Zhao, H., Zhao, H. and Guo, S. (2018), "Comprehensive Performance Evaluation of Electricity Grid Corporations Employing a Novel MCDM Model", *Sustainability Multidisciplinary Digital Publishing Institute*, Vol. 10 No. 7, pp. 2130. doi: 10.3390/su10072130.

Žižović, M., & Pamucar, D. (2019). New model for determining criteria weights: Level Based Weight Assessment (LBWA) model. Decision Making: Applications in Management and Engineering, 2(2), 126-137. doi.org/10.31181/dmame1902102z

Appendix 1

Table A. *Best* and *Worst* criteria determined by Experts 1-8

Criteria	Identified as *Best* by Expert	Identified as *Worst* by Expert
Operational (O)	2, 3, 4, 5, 6, 7	1
O1	1, 7	
O2	4, 8	
O3	2, 3, 5, 6	
O4		
O5		1, 3, 6
O6		
O7		4, 7
O8		5
O9		2, 8
Social (S)	8	2, 5, 7
S1		1, 2, 3
S2	3, 4, 6, 8	
S3	1, 5	7
S4	2, 7	4, 5, 6, 8
Management (M)	1	3, 4, 6, 8
M1	1, 4	
M2		1, 5, 8
M3	2, 5, 6, 7	3
M4	3, 8	6
M5		2, 4, 7

Table B. Pairwise comparison of main criteria for Expert 1

BO	**Operational (O)**	**Social (S)**	**Management (M)**
Best criterion: Management(M)	9	6	1
OW	**Worst criterion: Operational (O)**		
Operational (O)	1		
Social (S)	5		
Management (M)	7		

Table C. Pairwise comparison of operational sub-criteria for Expert 1

BO	**O1**	**O2**	**O3**	**O4**	**O5**	**O6**	**O7**	**O8**	**O9**
Best sub-criterion: O1	1	3	6	3	7	5	4	2	4
OW	**Worst sub-criterion: O5**								
O1	3								
O2	5								
O3	4								
O4	7								
O5	1								
O6	2								
O7	2								
O8	7								
O9	8								

Table D. Pairwise comparison of social sub-criteria for Expert 1

BO	**S1**	**S2**	**S3**	**S4**
Best sub-criterion: S3	6	2	1	5
OW	**Worst sub-criterion: S1**			
S1		1		
S2		5		
S3		8		
S4		3		

Table E. Pairwise comparison of management sub-criteria for Expert 1

BO	**M1**	**M2**	**M3**	**M4**	**M5**
Best sub-criterion: M1	1	6	4	5	8
OW	**Worst sub-criterion: M2**				
M1		8			
M2		1			
M3		7			
M4		6			
M5		4			

Table F. Main criteria and sub-criteria weights for each Expert with their final averaged weights

		E1 weights	E2 weights	E3 weights	E4 weights	E5 weights	E6 weights	E7 weights	E8 weights	**Average**
Main criteria	**O**	0.077	0.738	0.738	0.785	0.700	0.660	0.575	0.222	***0.562***
	S	0.163	0.083	0.179	0.148	0.100	0.240	0.100	0.694	***0.213***
	M	0.760	0.179	0.083	0.067	0.200	0.100	0.325	0.083	***0.225***
Operational sub-criteria	**o1**	0.226	0.061	0.071	0.083	0.090	0.068	0.241	0.111	***0.119***
	o2	0.122	0.086	0.106	0.243	0.181	0.058	0.100	0.250	***0.143***
	o3	0.061	0.310	0.325	0.111	0.293	0.309	0.060	0.067	***0.192***
	o4	0.122	0.107	0.085	0.042	0.060	0.189	0.100	0.083	***0.099***
	o5	0.029	0.143	0.032	0.166	0.090	0.030	0.149	0.167	***0.101***
	o6	0.073	0.143	0.071	0.055	0.060	0.058	0.075	0.056	***0.074***
	o7	0.092	0.072	0.106	0.022	0.072	0.136	0.026	0.131	***0.082***
	o8	0.183	0.054	0.061	0.166	0.032	0.102	0.100	0.111	***0.101***
	o9	0.092	0.024	0.142	0.111	0.120	0.051	0.149	0.024	***0.089***
Social sub-criteria	**s1**	0.070	0.070	0.053	0.160	0.222	0.186	0.197	0.133	***0.136***
	s2	0.300	0.140	0.601	0.587	0.167	0.492	0.296	0.567	***0.393***
	s3	0.510	0.233	0.208	0.200	0.542	0.237	0.070	0.222	***0.278***
	s4	0.120	0.558	0.139	0.053	0.069	0.085	0.437	0.078	***0.192***
Management sub-criteria	**m1**	0.527	0.120	0.133	0.406	0.249	0.164	0.121	0.172	***0.237***
	m2	0.055	0.103	0.267	0.125	0.053	0.098	0.202	0.052	***0.119***
	m3	0.182	0.550	0.050	0.250	0.408	0.410	0.477	0.259	***0.323***
	m4	0.145	0.179	0.417	0.167	0.166	0.082	0.151	0.414	***0.215***
	m5	0.091	0.048	0.133	0.052	0.124	0.246	0.050	0.103	***0.106***

Table G. Case company data provided for the implementation of the proposed manufacturing performance evaluation index system

Main Criteria	Wts	Sub-Criteria	Wts	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Operational	0.562	O_1	0.119	0.100	0.400	0.600	0.400	0.500	0.700	0.550	0.700	0.900	0.800	0.900	1.000
		O_2	0.143	0.100	0.400	0.600	0.400	0.500	0.700	0.550	0.700	0.900	0.800	0.900	1.000
		O_3	0.192	1.000	0.900	0.500	0.800	0.700	0.400	0.650	0.500	0.300	0.300	0.200	0.000
		O_4	0.099	0.500	0.550	0.700	0.600	0.700	0.800	0.900	0.900	0.950	0.950	1.000	1.000
		O_5	0.101	0.800	0.700	0.500	0.500	0.400	0.300	0.300	0.200	0.100	0.050	0.005	0.005
		O_6	0.074	0.600	0.650	0.700	0.700	0.750	0.800	0.850	0.900	0.950	0.990	0.990	0.990
		O_7	0.082	0.400	0.450	0.500	0.450	0.500	0.700	0.800	0.900	0.950	0.950	0.950	0.850
		O_8	0.101	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
		O_9	0.089	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Social (Stakeholder's)	0.213	S_1	0.136	0.800	0.800	1.000	0.000	0.000	0.000	0.000	0.000	0.100	0.000	0.000	0.000
		S_2	0.393	1.000	0.950	0.800	0.600	0.500	0.550	0.400	0.450	0.400	0.300	0.250	0.200
		S_3	0.278	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
		S_4	0.192	1.000	0.950	0.950	0.200	0.100	0.300	0.350	0.400	0.500	0.600	0.700	0.800
Management	0.225	M_1	0.237	1.000	0.900	0.850	0.700	0.750	0.650	0.600	0.550	0.500	0.650	0.450	0.400
		M_2	0.119	1.000	0.900	0.800	0.700	0.600	0.500	0.400	0.300	0.200	0.100	0.005	0.005
		M_3	0.323	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.950	1.000	1.000	1.000	1.000
		M_4	0.215	0.500	0.600	0.900	0.700	0.800	0.950	0.800	0.900	0.950	0.950	0.950	1.000
		M_5	0.106	0.000	0.100	0.400	0.300	0.450	0.600	0.500	0.550	0.700	0.750	0.800	1.000

**Data is from April 01, 2017 to March 31, 2018 and the value 1 is considered the highest.*