Sustainable Performance Measurement in Manufacturing Process of Textile Industry by using Analytical Hierarchy Process

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Abstract

Sustainable manufacturing practices in the textile industry have become a crucial topic for managers of manufacturing organizations to remain competitive in the market. The textile sector is well known for consuming a large amount of natural resources, raw materials, energy, and fossil fuels, and for being a significant contributor to pollution. Evaluating the sustainability performance of textile manufacturing companies is therefore important. To address this, a study has developed an Analytical hierarchy process (AHP)-based model for assessing sustainable manufacturing performance. The study identifies performance measures for sustainable manufacturing based on economic, environmental, social, and technical factors, and confirms their relevance through a survey. The findings demonstrate that all measures are extremely important and are suggested as key performance measures for the textile sector. Then, AHP is used to evaluate sustainable manufacturing performance based on these measures, resulting in quality and employee ranking as the highest critical factors, and complexity and flexibility as the least important. The study offers a hierarchical model for evaluating the sustainability performance of five case organizations, guiding production managers to assess the strengths and weaknesses of their organizations. These findings encourage researchers and practitioners to study more about sustainability evaluation.

Keywords—Sustainable manufacturing, performance measures, evaluation, Analytic Hierarchy Process (AHP)

1 Introduction

Globally expanding manufacturing organizations have contributed in improving quality of life while having a negative impact on the environment [1], [2]. The climate and the strength of living structures are adversely affected overwhelmingly by air contamination that are released by manufacturing organizations [3], [4]. Manufacturing organizations are being forced to develop new strategies to achieve an appropriate level of growing market and consumer demand for sustainable products, which results of depletion of natural resources or related legal requirements. Additionally, they need to increase their enterprise profits while minimizing their negative effects on the environment. Instead, they are expected to establish a workplace that is appealing to employees and emphasizes cooperation, education, and the growth of competencies [5]. Government and non-governmental groups force contemporary firms to diminish adverse effects on the environment and advance safety of workforce [6]. Considering these perspectives, many businesses have started reorganizing their current manufacturing methods to make them more sustainable [7].

One of the key concerns for the textile industry is sustainable production. Population growth has increased textile production and consumption nationwide, which results in an expanding global economy [8]. As per the report, the global textile industry generates an annual revenue of USD 3 trillion, which accounts for 2% of the total worldwide global domestic product (GDP). Annually, over 100 million metric tons of textile products are produced, making the garment and textile sector one of the largest in the world [9], [10], [11] demonstrate that the textile sector should utilize more environmentally friendly materials. According to [12], practically all production sectors in developed countries, including the textile industry, have been nearly automated. Production of textiles has become

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more affordable after adopting automated processes and energy cost reductions due to sustainable business practices. If we consider the year 1960 to be the beginning of advanced manufacturing systems, several different tactics fall under that general heading. For instance, Tao, 2017 [13] categorize significant number of manufacturing methods; the list encompasses flexible, computer-integrated, cloud, additive, virtual, concurrent engineering, manufacturing grid, crowd sourcing, sustainable, agile, dynamic alliance, networked, lean, green, product service system, and reconfigured manufacturing. In terms of benefits, there are two primary categories of manufacturing technology. The first approach category is referred to as "technological" approach, and it includes the first eight approaches: flexible, computer integrated, cloud, additive, virtual, concurrent engineering, manufacturing grid, and crowd sourcing. The technological group's aim is to increase productivity and financial success. The second category focuses on strategies that are friendly to the environment, such as lean, green, and sustainable manufacturing techniques. The remaining five strategies will need more research since they do not clearly fit into either group. Apparently, benefits from the second category place more emphasis on social and environmental concerns rather than financial ones. Most studies focus on just one of the manufacturing techniques mentioned above. [14] focused on energy optimization in sustainable manufacturing but excluded other technological approaches. For optimal value generation, companies should adopt both strategy categories rather than maintaining a focus on one category to the exclusion of the other. Therefore, research is required that, as this study aims to combine technological techniques with environmental and societal issues. The integration of manufacturing with sustainable business practices can lead to an examination of four aspects: environmental, technical, technological, and social. These four aspects result in following research questions:

RQ1: What returns do advance sustainable manufacturing and integration of sustainable methods have?

RQ2: What are common drivers that contribute to effective adoption of sustainable manufacturing?

RQ3: Which common drivers have major influence on advanced sustainable manufacturing?

Businesses that use sustainable methods can enhance their market share, profit margins, and quality of their products. Consequently, developing sustainable manufacturing has become a major global problem [15].

The first of three research issues listed above had already been discussed, hence the other two are considered to have more significance. To address these important concerns, this study suggests a framework model that examines complexities that support sustainable manufacturing.

The purpose of this study is to create and analyze performance metrics for production process of textile sector in terms of sustainability. The assessment of performance metrics is carried out in two phases: first, determining set of performance metrics relevant to performance of textile sector's manufacturing, and second, evaluating process. In this study, the sustainability performance of textile manufacturing processes is identified. In order to assess the effectiveness of sustainable production in textile sector, this study suggests an AHP-based methodology. A survey is conducted to approve compatibility of initial metrics with manufacturing practices. The evaluation of sustainable manufacturing performance is based on these metrics using the AHP model.

2 Research Methodology

The research approach involves identifying performance metrics for sustainable manufacturing, which includes validation and evaluation of these metrics. The preferred metrics are then verified by experts. Finally, to evaluate these indicators, AHP is used. The research methodology for this study is depicted in the flowchart in Figure 1.

The advantages of this technique are that it organizes an unstructured problem into structured hierarchy of decisions, gathers additional input from experts through comparing groups of elements pairwise, computes weights for elements, and checks consistency of ratings made by expert panels or decision makers using consistency measure [16]. The procedure of step-by-step identification and evaluation is detailed in the next section.

The main objective is to assess performance metrics for sustainability evaluations in the textile industry. In the evaluation process, sustainable manufacturing performance metrics in textile sector are identified, selected, prioritized, and modeled. Furthermore, evaluation models are utilized to determine both individual and overall performance evaluations, considering effectiveness of performance metrics. Companies under consideration are leading garment manufacturers and suppliers in the country and abroad, with certifications from prestigious standards organizations such as ISO 9001 and ISO 14001 and adherence to government regulations for safety. These companies are seeking metrics that can assess their sustainability performance effectively. To compare the performance

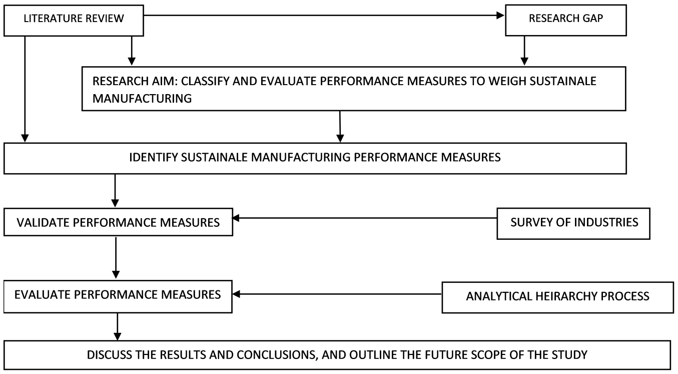

Fig. 1: Theoretical framework of Analytical Hierarchy Process (AHP)

of different companies, this study evaluates these performance metrics. The following sub-sections describe comprehensive evaluation procedure in detail.

2.1 Finding Sustainability Performance Metrics

The research establishes performance criteria to assess sustainable manufacturing practices within the textile sector. The criteria are developed by combining standard manufacturing performance measures with those that focus specifically on sustainability. The metrics incorporate sustainability aspects, including economic viability, environmental impact, social responsibility, and technical efficiency. This leads to total of four main criteria and 16 sub-criteria, as displayed in Table 1.

TABLE 1: Performance metrics for initial evaluation of sustainable manufacturing

Criteria	Sub-Criteria
Economic	Cost
	Quality
	Delivery
	Flexibility
Environmental	Pollution
	Resource Consumption
	Waste
	Biodiversity
Social	Employee
	Supplier
	Complexity
	Health Risk
Technical Factor	Maintenance Requirement
	Durability
	Energy Consumption
	Upgradability

2.2 Conducting Industry Survey

This study aims to confirm preliminary measures in the production procedure of textile sector. In total 150 surveys are distributed; 98 responses are returned with a response rate of 65.3%. Three of the answers are not considered as they were missing information. The survey participants are asked to rate their perspective to the importance level of the performance measures, using an AHP scale ranging from 9 (extremely important) to 1 (equally important). The mean importance values extended from 1.939 to 12.513, as shown in Table 2.

TABLE 2: The importance of performance measures in sustainable manufacturing with regards to their weighting

Rank	Measure	Mean
1	Quality	12.513
2	Employee	11.407
3	Cost	11.335
4	Maintenance Requirement	10.191
5	Resource Consumption	7.465
6	Supplier	7.423
7	Durability	7.020
8	Waste	4.887
9	Pollution	4.651
10	Health Risk	3.957
11	Delivery	3.252
12	Energy Consumption	2.780
13	Upgradability	2.745
14	Biodiversity	2.375
15	Complexity	1.988
16	Flexibility	1.939

As indicated by data in Table 2, the highest rated factor is quality, with an average score of 12.51334898. This is achieved by employee satisfaction with an average importance value of 11.40764636. The subsequent important factors are cost, maintenance requirements, resource consumption, supplier, and durability to specification with importance mean of 11.3359319, 10.19103943, 7.465251281, 7.423312683 and 7.020954651 respectively. The highest-ranked measures are found within categories of quality and employee and fall under criteria of economic and social. Alternatively, while complexity and flexibility are seen as less significant, but still maintain a level of importance. Hence, findings indicate that all initial metrics are considered important, resulting in the suggestion of four criteria and 16 sub-criteria as performance metrics for assessing sustainable manufacturing in textile sector.

2.3 Constructing a Model for Assessing the Performance of Sustainable Manufacturing

In this study, a technique for evaluating the effectiveness of sustainable manufacturing in textile industry are presented. The Analytic Hierarchy Process (AHP) is utilized to develop evaluation model. This has involved creating a hierarchy, determining relative importance of each factor, assessing metrics, calculating scores for each company, and arranging companies based on scores. Further details are described in the following section.

3 Development of AHP to Assess Sustainable Manufacturing Performance

Analytic Hierarchy Process (AHP), first presented by Thomas L. Saaty in 1971, has evolved into a widely used method for solving problems in multiple criteria decision making (MCDM). It is a method of decision making that can be used in a variety of sectors and was developed to assist in finding answers to difficult situations with multiple criteria [17]. AHP has long been recognized as an essential resource for researchers and practitioners who are studying decision making and observing management ideas [18]. AHP is flexible and prearranged problem solving approach that can signify the parts of complicated problem [16]. Cheng, et al [18], highlighted a number of advantages of the AHP technique. AHP is particularly useful in situations where there are multiple criteria to consider and where subjective judgments need to be made. It provides a structured framework for decision making and allows for the incorporation of both quantitative and qualitative data. The steps involved in using AHP to assess the effectiveness of sustainable manufacturing in the textile industries are outlined below. Firstly, the unstructured problem is organized into a clear decision hierarchy. Secondly, experts or decision-makers provide additional information by comparing different groups of items through pairwise comparisons. Thirdly, the elements are assigned weights through calculations. Fourthly, a consistency metric is used to verify that the ratings provided by experts and decision makers are consistent.

3.1 Construct the Hierarchy

A hierarchy is formed based on key performance criteria designated for sustainable manufacturing. This structure consists of four groups organized order, including goal, criteria, sub-criteria, and alternatives. The objective of the hierarchy is to evaluate the performance of sustainable manufacturing. The next level comprises of four criteria: environmental, economic, social, and technical. The third level of structure includes sub-criteria that describe each of four criteria, for a total of 16 sub-criteria. The alternatives that the decision-maker must consider are at the bottom of structure and are represented by companies being evaluated and compared. The entire structure is depicted in Figure 2.

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3.2 Determine Relative Weight

The weight of performance measures are determined after a hierarchical model is developed. A survey is designed to gather input from a group of experts to assess the sustainability, which includes matrices for pairwise comparisons. The experts are requested to in-person meetings and provide their opinions on importance of each performance indicator using AHP scale, where 9 represents ”extreme importance”, 7 represents ”very strong importance”, and so on. The survey results are analyzed through frequency analysis, and the AHP method is used to determine weighting of performance measures. The same procedure is repeated to find other weights [19]. Both sustainability parameters and performance measures have assigned weights. The results of analysis are shown in Table 3, which presents calculated weights of performance measures for evaluating sustainability in textile manufacturing. Table 3 shows the relative significance of one performance measure in comparison to others. Among sustainability factors, economic sustainability has the highest weight with 42.6435% importance, followed closely by quality with 43.087% weight, indicating it is the most essential performance measure for economic sustainability. In the case of social sustainability,

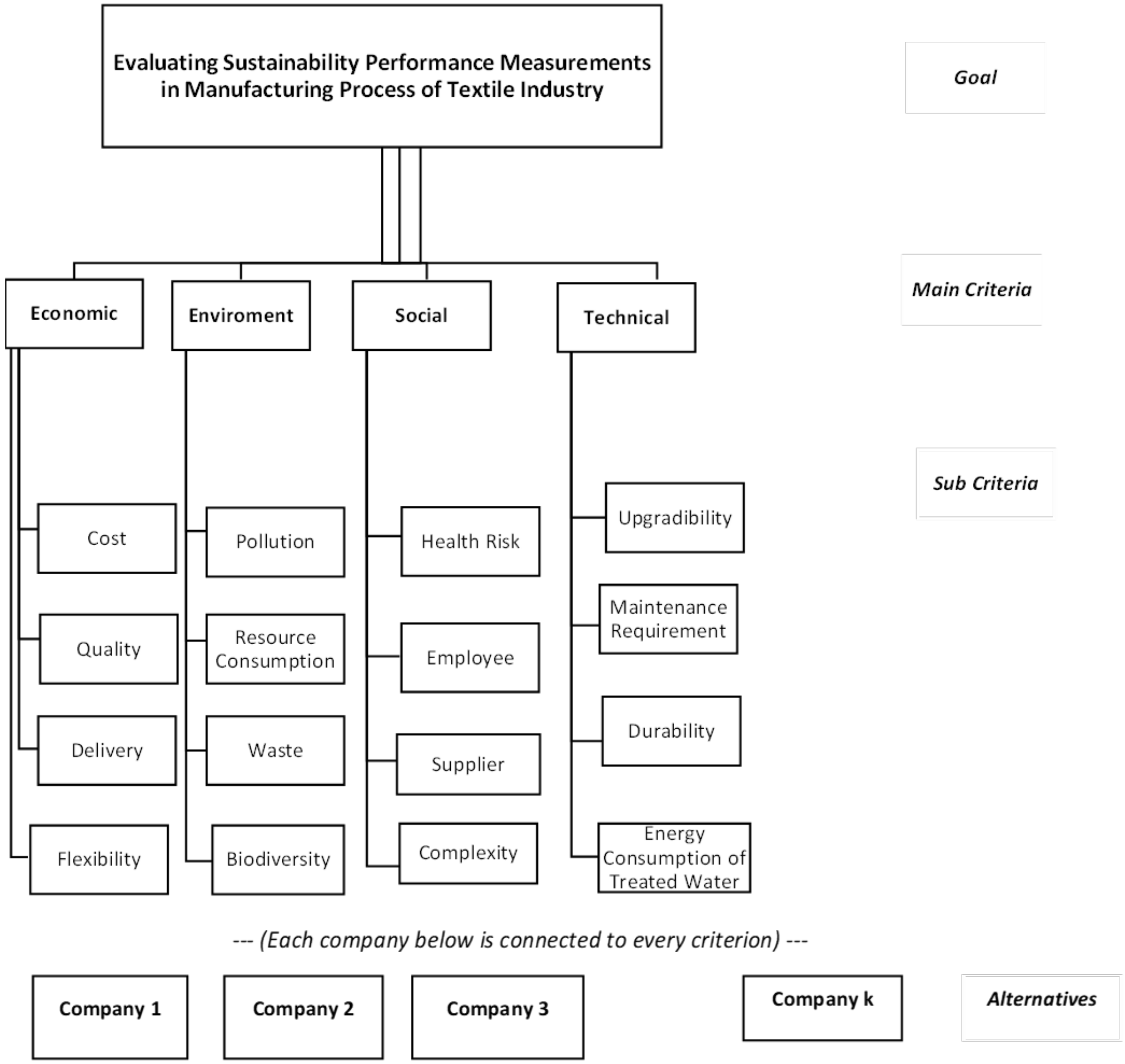

Fig. 2: The hierarchy structure of sustainable manufacturing performance measurement for manufacturing process of textile industries.

contributing to employees is considered the most important performance measure with weight of importance of 46.042%. Resource consumption is considered significantly more important performance measure for technical sustainability with weight of importance of 38.521%. Additionally, when it comes to technical sustainability, maintenance requirements are considered the most crucial dimension with a weight of importance of 44.818% over other factors.

3.3 Evaluating Performance Measures for Sustainable Manufacturing

The following step in evaluating sustainability of manufacturing performance involves assigning scores to measures. This study uses a scale from 1 to 10, with 1 indicating extremely poor performance, 2 representing a significant lack of sustainability, 3 signifying a low level of sustainability, 4 signifying low fairness, 5 representing moderate fairness, 6 representing high fairness, 7 signifying low sustainability, 8 signifying for moderate sustainability, 9 symbolizing high sustainability, and 10 signifying exceptional performance.

3.4 Computing the Scores of Companies

The process of determining the score for organizations involves combining performance ratings with appropriate weights for each factor. The result is company score, which includes both overall score

TABLE 3: The importance of performance measures in sustainable manufacturing with regards to their weighting

Criteria	Weight (%)	Sub-Criteria	Weight (%)
Economic	42.64356129	Cost	39.03354933
		Quality	43.08780513
		Delivery	11.19862511
		Flexibility	6.680020433
Environmental	23.76709729	Pollution	24.00297662
		Resource Consumption	38.52156959
		Waste	25.21814485
		Biodiversity	12.25730894
Social	13.30450561	Employee	46.04268671
		Supplier	29.96141795
		Complexity	8.024508926
		Health Risk	15.97138642
Technical Factor	20.28483581	Maintenance Requirement	44.81897706
		Durability	30.87732196
		Energy Consumption	12.22828837
		Upgradability	12.07541262

and individual scores for each aspect and criterion. Based on these scores, organizations have classified into four levels of performance:
Poor performance: If $1 \leq$ score ≤ 4
Fair performance: If $4 <$ score ≤ 7
Good performance: If $7 <$ score ≤ 9
Excellent performance: If score ≥ 9
The organizations are then arranged in order of decreasing score, both overall and for each individual factor and criteria. The organization that scores highest is considered to have the most exceptional performance.

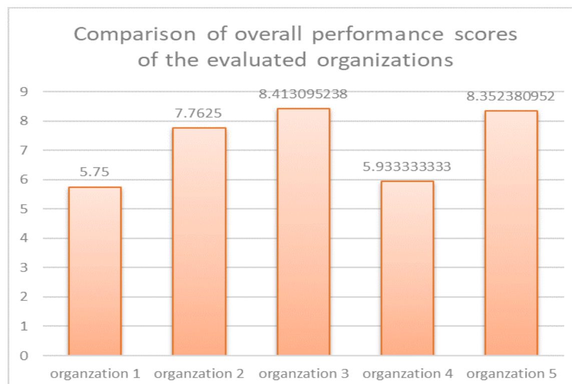

Fig. 3: Comparison of overall performance scores of the evaluated organizations

4 Results and Discussion

The performance of five textile manufacturing organizations have been evaluated using assessment techniques. The rating values and calculated weights of the performance measures were used to determine organizations' performance scores, which were calculated both overall and individually. The results show that Organization 3 has the highest performance score of 8.413095238, which placed it in the excellent performance category. In contrast, Organization 1 scored of 5.75, placing it in the fair performance category.

Table 4 shows individual scores calculated for each sustainability factor, showing diverse range of rankings and performance levels for the organizations. Organization 1, despite having a low overall sustainability score, does not necessarily have the lowest score in all sustainability parameters. Conversely, organization 3, which has a high sustainability performance level, should receive priority in sustainability decisions (as shown in Fig. 3). The results suggest that organizations with low overall sustainability scores may not have poor performance in every category. To make informed sustainability choices and improve sustainability, organizations should first identify their areas of weakness and focus on improving them. This will result in a higher overall sustainability level in their textile production process.

5 Conclusion

Manufacturing firms in the textile industry use fossil fuels, natural resources, and energy, which result in the release of significant levels of pollutants into the environment. To address this issue,

TABLE 4: Comparison of individual performance scores of organizations

Comparison	Individual Performance Scores			
	Economic	Environmental	Social	Technical
Organization No. 1	6.02	6.26	8.01	5.70
Organization No. 2	7.09	6.91	7.06	7.53
Organization No. 3	8.17	5.00	7.68	6.27
Organization No. 4	4.67	5.33	4.67	5.00
Organization No. 5	6.88	9.46	6.78	6.90

performance measures for determining sustainability level of textile manufacturing organizations are established and analyzed. The literature review conducted as part of this study leads to determination of initial performance measures, which are confirmed by industrial experts. The final evaluation model, created to assess sustainability performance of textile manufacturing processes, is based on four sustainability criteria and sixteen performance measures. A hierarchical model is developed using AHP methodology, and performance measures receive their importance weights through contribution from experts. The overall and individual performance scores of organizations were evaluated by experts. The study analyzes sustainability performance of five textile manufacturing organizations and provided production managers with guidelines to improve sustainability performance. This study inspires further research and investigation into industrial sustainability evaluation among practitioners, decision makers, and researchers.

Limitations and Future Work

The objective of the current study is to examine performance measures and evaluate performance level of textile manufacturing firms by utilizing input from industry experts in evaluation process. The evaluation results and the sustainability assessment process may both be affected by preference in input. The study is being carried out in the textile industry, using data obtained from textile manufacturing organizations, and the assessment approach may not be relevant to other types of companies. However, assessment models used in five various textile manufacturing organizations suggests that results can be generalized to similar organizations. The sixteen performance metrics selected for this study are flexible and can be enhanced based on difficulties faced by individual companies. The current study deals substantial approaching for future academic and practitioner research to assess sustainability of organizations.

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