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Article

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Cogent Business & Management

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Suggested Citation: Hashim, Muhammad et al. (2021) : Unlocking the sustainable production indicators: Novel TESCO based fuzzy AHP approach, Cogent Business & Management, ISSN 2331-1975, Taylor & Francis, Abingdon, Vol. 8, Iss. 1, pp. 1-18, <https://doi.org/10.1080/23311975.2020.1870807>

This Version is available at:

<https://hdl.handle.net/10419/270201>

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To cite this article: Muhammad Hashim, Muhammad Nazam, Muhammad Abrar, Zahid Hussain, Muhammad Nazim & Rizwan Shabbir | (2021) Unlocking the Sustainable Production Indicators: A Novel TESCO based Fuzzy AHP Approach, Cogent Business & Management, 8:1, 1870807, DOI: [10.1080/23311975.2020.1870807](https://doi.org/10.1080/23311975.2020.1870807)

To link to this article: <https://doi.org/10.1080/23311975.2020.1870807>



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Received: 14 October 2020
Accepted: 25 December 2020

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Reviewing editor:
Albert W. K. Tan, Education,
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OPERATIONS, INFORMATION & TECHNOLOGY | RESEARCH ARTICLE

Unlocking the Sustainable Production Indicators: A Novel TESCO based Fuzzy AHP Approach

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Muhammad Nazim⁴ and Rizwan Shabbir³

Abstract: Sustainable production is becoming an important slant through which business enterprises prepare for achieving sustainable development goals. The concept of sustainable manufacturing deals with the development of various items that may utilize minimum resources and are safer for the society at a reasonable price. The present research problem explores and evaluates the production indicators pertaining to the achievement of sustainability in a textile supply chain. In this research, five main indicators and twenty five sub-indicators were determined through extensive review of literature and experts confirmation. This study proposes a novel TESCO-based fuzzy AHP approach for the evaluation of sustainability dimensions of textile sector under uncertain environment. This paper investigates the key sustainable dimensions based on technical (T), ecological (E), socio-economic (S), core competencies (C) and operational (O) considerations to prioritize



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Dr. Muhammad Hashim is an Assistant Professor, Director “program of Textile Management and Marketing”, and Group Leader “business analytics and decision research group” at department of Management Sciences, National Textile University Faisalabad, Pakistan. He did his PhD in Management Sciences and Engineering and research focuses on Marketing and Management, operations and supply chain management, Sustainability, Lean Manufacturing, fuzzy set theory and Multi Criteria Decision Making. His works have been published in peer-reviewed national and international journals such as the *Journal of Enterprise Information Management*, *Journal of Industrial Engineering and Management*, *International Journal of Information Systems and Supply Chain Management*, *International Journal of Supply and Operations Management*, *Journal of Managerial Sciences*, *SAGE Open*, *Industria Textila*, *China Communications*, *Environmental Hazards*, *Measurement*, *Energy*, *Quality and Quantity*, etc. He has been invited as a Guest Speaker and for research paper presentation at different international universities (Monash University Australia, Kanazawa University, Japan, Karlsruhe Institute of Technology Germany, Academy of Economic Studies of Moldova, Azerbaijan State University of Economics, etc.

PUBLIC INTEREST STATEMENT

Sustainable production is becoming an important slant through which business enterprises prepare for achieving sustainable development goals. The present research aims to explore and evaluate the production indicators pertaining to the achievement of sustainability in a textile supply chain. This research contributes to literature, relevant to the identification and prioritization of key sustainable production indicators. This paper investigates the key feasible sustainable dimension based on technical, ecological, socio-economic, core competencies and operational (TESCO) considerations to prioritize the production indicators. This study provides several theoretical as well as practical implications for the managers in the concerned industries. The outcome of this research would be supportive measures for the stakeholders by providing insights regarding physical distribution and distribution of products for achieving sustainable development goals.

the sustainable production indicators (SPIs). The fuzzy analytical hierarchy process (FAHP) approach has been applied to compute the weight vectors of dimension impacting the (SPIs). The findings depict that technical indicators have significant impact whereas operational indicators have the least impact in the decision-making process of a textile sector. Furthermore, a sensitivity analysis is applied to check the robustness among the criterion ranking and suggest possible measures to improve operational business excellence. Finally, the paper brings out a more systematic decision support toolkit and implications for the concerned stakeholders to formulate the policies regarding physical production and distribution of products.

Subjects: Customer Relationship Management (CRM); Enterprise Resource Management (ERP); Supply Chain Management

Keywords: sustainable production indicators; fuzzy AHP; sensitivity analysis; textile sector

1. Introduction

The concept of sustainable manufacturing basically consists of three elements: (1) the selection of suitable measures for assessing manufacturing sustainability (2) carefully identify the poor areas (3) adaptations to improve manufacturing sustainability. Strategically, to adopt the strategies of sustainable manufacturing is very important at all levels, i.e., large, small, and medium industries. It can vary from industry to industry due to the different organizational characteristics for example, management opinions, limited finance, and resources, level of flexibility, structure, lack of skilled labors, few customers and markets. The concept of sustainable manufacturing deals with the development of various items that may utilize minimum resources and are safer for the society at a reasonable price. Seuring and Müller (2008) tended to the time and complexity effects consequences for the presentation of green items in the German textile business setting. It was additionally referenced that execution of corporate social responsibility (CSR) practices would benefit the organization financially and help in accomplishing a sustainable textile and clothing production network of worldwide extents. Gümüş and Akbal (2011) assessed the procedures used and their potential natural effects for the assembling of textile items, for example, rayon, polyester, nylon, fleece, and cotton. It was featured that for the effective execution of environmental friendly practices, appropriate coordination is required between the administration associations, ventures, and buyers. As it is a very important case for many producing plants for reducing resource wastages and consumption and related costs. Alkaya et al suggested that there are two main economic advantages derived through implementing the sustainable textile production: it would reduce the production cost. It also reduced the health and environment impacts on industrial employees and society. Significant number of studies investigated that it is the potential of sustainable production to achieve water savings between 75 and 79% (Alkaya & Demirer, 2014; Dubey et al., 2015; Gupta et al., 2015; Hoseini Shekarabi et al., 2019; Lieder & Rashid, 2016; Linton et al., 2007).

Recently, sustainability has gained popularity among academia and industry, and noted as a crucial matter in our everyday life (Gharai et al., 2019; Nazam et al., 2020; Marques, 2019; Kazemi et al., 2018). Sustainable textile production and consumption are treated as sub-part of sustainable growth and development (Duan et al., 2018; Rabbani et al., 2020; Roberts & Ball, 2014). The main focuses are producing goods or adopt manufacturing processes that are environment friendly, conserve energy and natural resources. This approach consists of three constituents: (1) to identify the critical indicators for measuring manufacturing sustainability, (2) assessment tool to identify the weak areas, and (3) to adjust the system for enhancing manufacturing sustainability. Nowadays, it is very important to make product for environmental as well as economically feasible for the organizations (Giri & Bardhan, 2014; Gharai et al., 2019; Yin et al., 2016). Globalization has also forced organizations to enhance their environmental performance. Significant numbers of studies have been carried on sustainable manufacturing practice in the context of developed

countries but very few studies have investigated the sustainable manufacturing practices in the context of developing countries, particularly in Pakistan. The main objective of present study is to establish most relevant and important sustainable production measures regarding economic, environmental, and social factors that can help Pakistan textile producers to gain competitive edge. The importance of sustainable production technique was recognized in all sectors of textile production especially processing units all over the world. For the implementation of this sustainability concept, different techniques/technologies have conducted to reduce and control the effect of chemical, wastewater and energy demand of organizations.

In this backdrop, the textile industries play a significant role in sustainable production development. The practices of sustainable manufacturing are getting popularity in Pakistan. It is the result of increasing pressure from government policies, highly demanded market, customer knowledge, reducing manufacturing costs, increasing and maintain product quality, appealing foreign investment, intellect the economic benefits, and knowledge of the circular economy. The Government of the Punjab (environmental protection department) makes rules and regulations for reducing and controlling the waste of textile and other sectors as well that are directly contributing to environmental and health issues in the country. It is also a part of sustainable manufacturing processes and physical distribution of products to the end consumers. The successful implementation of sustainable production would reduce the costs and improve quality management, ultimately, will increase direct foreign investment in Pakistan (Baldwin et al., 2005; Nazam et al., 2015; Roberts & Ball, 2014; Sarkar & Giri, 2018).

The remainder of the present study is structured into seven sections and sub-sections. Section 2 discusses the detailed review of literature on significant indicators for enhancing the sustainability of production practices under uncertain supply chain environment. The next Section 3 elaborates the proposed research methodological approach used in conducting the research, which followed the steps of proposed framework in Section 4. The discussion of findings along with sensitivity analysis is presented in Section 5. In Section 6 implications of the research are discussed. Finally, Section 7 summarizes the concluding remarks, limitation, and future research avenues.

2. Literature review

The approach of sustainable production was successfully realized in dozens of textile industries worldwide. It is very important in manufacturing industries related to textiles and clothing (Álvarez et al., 2017; Gharaei et al., 2019; Shah et al., 2020; Tan et al., 2011). Large-scale industries are developing their capabilities required to accomplish the sustainable manufacturing. Hillary (2004) determined both barriers and drivers for improving the environmental management system of small and medium enterprises (SMEs). The scholar investigated lack of knowledge, implementation cost, training and development, firm size, and characteristics of SMEs are recognized as barriers for sustainable practices (Alayón et al., 2017; Giri & Masanta, 2018). Hoque and Clarke (2012) investigated that chemical utilization and related polluted heap of wastewater can be diminished in all procedure of textile organizations. In addition to the ability to use chemical products and water, the energy efficiency in textile industry get strongly influenced by various environmental/biological factors studied by experienced researchers. Palamutcu (2010) have emphasized that knowledge and awareness about energy efficiency in textile producer organizations is not yet at the required level and detailed measurement needs to be presented and updated. Some researchers have described that a methodology developed with seven-step approaches for the textile industry has led to a significant reduction in the use of energy.

Gupta et al. (2015) investigated the relationship between sustainable production and business performance using the structural equation model (SEM). Models include path analysis, multiple regression analysis, and confirmation of validation factors. Typically, the positive impact of sustainable production is determined by the performance of the company. According to the results, the steps required for partners to make the minimum effort to low-cost measure have higher contribution to performance and include more short-term financial implementation, compared to

high-cost measures. Hillary (2004) discovered the lack of knowledge, training, implementation cost, customers, government, local community, employees, insurers, banks, and larger companies in implementations of sustainability in small industries. The size and characteristics of small and medium industries are also acknowledged as barriers in adoption of sustainable practices (Gharai et al., 2019; Giri & Masanta, 2018; Lepoutre & Heene, 2006). Recently, small and medium industries are moving toward green initiatives for surviving in the market and getting competitive edge in the global market (Lee et al., 2013). The research study conducted in Philippines concluded that the environmental indicators are capable to show up the real environmental performance. Joung et al. (2013) developed a framework for sustainable production system based on environmental standards and introduced a decision-making model for applying in small and medium industries and the basic purpose was to manage the sustainability aspects (social, environmental, and economic) within manufacturing industries.

2.1. Problem statement

The textiles industry plays a very critical role for both the industrialist and underdeveloped economies, contributing both to improve living standards and employment. Pakistan is the 8th largest exporter of textile products in Asia. In the world, it is 4th largest producer of cotton and ranked at 3rd level in yarn production. In Pakistan, textile sector has a fragmented and complex manufacturing system among the operations like yarn, fabric production for apparel, and industrial goods. It includes a huge amount and different kinds of raw material, chemicals, water, and energy are used in production operations. Therefore, relatively high quantity of waste emissions that significantly contribute to environmental risks and human health as well. Amongst the industrial sectors, textile is ranked at highest level in polluting; consider the wastewater. Water pollution has become a major problem in Pakistan. Although large textile units have been developed their capabilities for achieving the good level of sustainable manufacturing but the small units are still in progress due to absence of finance, human resources, and awareness for the required changes for sustainability within the organizations (Gharai et al., 2019; Lee et al., 2013). Due to environmental and water issues the Faisalabad city of Pakistan is facing very alarming situation. The society facing serious health issues like hepatitis c and cancer, the major source of these issues are textile manufacturing industries. The literature on sustainable production from Pakistan perspective is still very limited and has not been looked at from the textile industries point of view. Based on above research highlights, this study unlocks key indicators considering the operations and production management aspects in the textile sector. This empirical research mainly focuses on important aspects regarding the prioritization of critical success factors within a supply chain environment. This study bridges the gap to determines the key indicators for achieving sustainable operational excellence in a Pakistani context.

2.2. Research gap

The increase in demand required the manufacturing industries to expand their production capacity and focus on sustainability for meeting the customer demands. Currently, due to the bad situation of corona patients in China and India, many customer orders are shifting to Pakistan. Currently, customers are looking for suppliers who are using sustainable production, sustainable packaging, and sustainable transportation ways for delivering customer orders. Malek and Desai (2019) conducted an extensive literature review (541 research papers are selected from journals on SCOPUS database). This study concluded that the focuses of research were on food sector (2.96%), steel (2.77%), and chemical (2.77%) industries. Furthermore, 63.40% of studies were conducted in developed countries, 36.6% of studies are conducted from developing countries and there is no single study cited from Pakistan. This study filled the existing gap regarding the identification of key sustainable production indicators and their categorization that are very critical in the context of developing country.

Significant numbers of literature are available discussed on industrial economic performance. Due to globalization and changes in business environment as well as society pressures change the way of business in the market. In a result, the concept of sustainability has expanded and includes

the environment impact and social performance aspects of industries (Gupta et al., 2015). It becomes very important to explore the sustainable way of manufacturing process and the assessment of sustainability in manufacturing industries. Academician used multiple methods and simulation techniques for the assessment of sustainability. Nazam et al. (2015) developed a novel fuzzy AHP-TOPSIS model for the adoption of green supply chain in textile industry to achieve sustainable business goals. Hashim et al., (2017) proposed an optimization model for manufacturing industries for selecting strategically sustainable supplier. They discussed product design sustainability model in social, economic, and environmental aspects for assessing product sustainability. The method, which is used for assessing sustainability in manufacturing industries

Table 1. Unlocking the key indicators of SPIs in a textile supply chain

| Domains of Sustainable Production | Codes | Key Sustainable Production Indicators | Brief descriptions | Sources |
|--|--------------|--|---|---|
| Technical (T) | T1 | New value creation and radical change | Technical aspects like modular structures, co-creation, create deep product satisfaction and the sources of renewable energy conservation lead the manufacturing industries to sustainable development. | Athar et al. (2019); Niinimäki & Hassi (2011); Gupta et al. (2015); Joung et al. (2013); Sáez-Martinez et al. (2016). |
| | T2 | Consumers' interest in the design strategies | | |
| | T3 | Renewable energy conservation | | |
| Ecological (E) | E1 | ISO Certification | Ecological sustainability can be define as an environment where industries try to reduce the impact organizational operations by saving energy, employees, community, reducing emissions, and less use of natural resources. | Elsahida et al. (2020); Moreno-Sader et al. (2020); Krolczyk et al. (2019); Abreu et al. (2017); Saswattecha et al. (2017); Joung et al. (2013); Lee et al. (2013); Rauch et al. (2016); Kreiger and Pearce (2013); Kreiger and Pearce (2013) |
| | E2 | Waste material ratio | | |
| | E3 | Water consumption | | |
| | E4 | Waste water ratio | | |
| | E5 | Pollution (CO2 emission) | | |
| | E6 | Renewable energy ratio | | |
| Socio economic (S) | SE1 | Investment | Produced environment friendly product and meet the customer satisfaction while minimizing environmental impact and maintaining social and economic benefits. The capacity building of employees in terms of skills, knowledge and creativity is an important element. | Elsahida et al. (2020); Joung et al. (2013); Rauch et al. (2016) |
| | SE2 | Profit | | |
| | SE3 | Community involvement | | |
| | SE4 | Training and Development | | |
| | SE5 | Labor intensity | | |
| | SE6 | Employee turnover ratio | | |
| | SE7 | Customers' satisfaction | | |

(Continued)

Table 1. (Continued)

| Domains of Sustainable Production | Codes | Key Sustainable Production Indicators | Brief descriptions | Sources |
|--|--------------|--|--|---|
| Core-competencies (C) | C1 | Flexibility | In current competitive environment, organizations need to continuously change paradigms of production and focus on faster delivery system. There is a need to introduce new and innovative ways for improving quality and flexibility of operations. | Rauch et al. (2016); Baines et al. (2012) |
| | C2 | Responsiveness | | |
| | C3 | Quality | | |
| | C4 | Research and development | | |
| Operational (O) | O1 | Reused material ratio | Industries are becoming more aware of their operations impact on society, planet and profitability with increasing pressure of customers and climate changes issues and their accountability regarding consumptions and environment. | Elsahida et al. (2020); Moreno-Sader et al. (2020); Abreu et al. (2017); Rauch et al. (2016); Zanetti et al. (2015) |
| | O2 | Recyclable material ratio | | |
| | O3 | Hazardous material management | | |
| | O4 | Cleaner Production | | |
| | O5 | Operation and maintenance Cost | | |

based on human subjectivity or input data based on human reasoning. It is mostly imprecise or fuzzy in nature. A glimpse of indicators supporting the sustainable production in a textile supply chain is given in [Table 1](#).

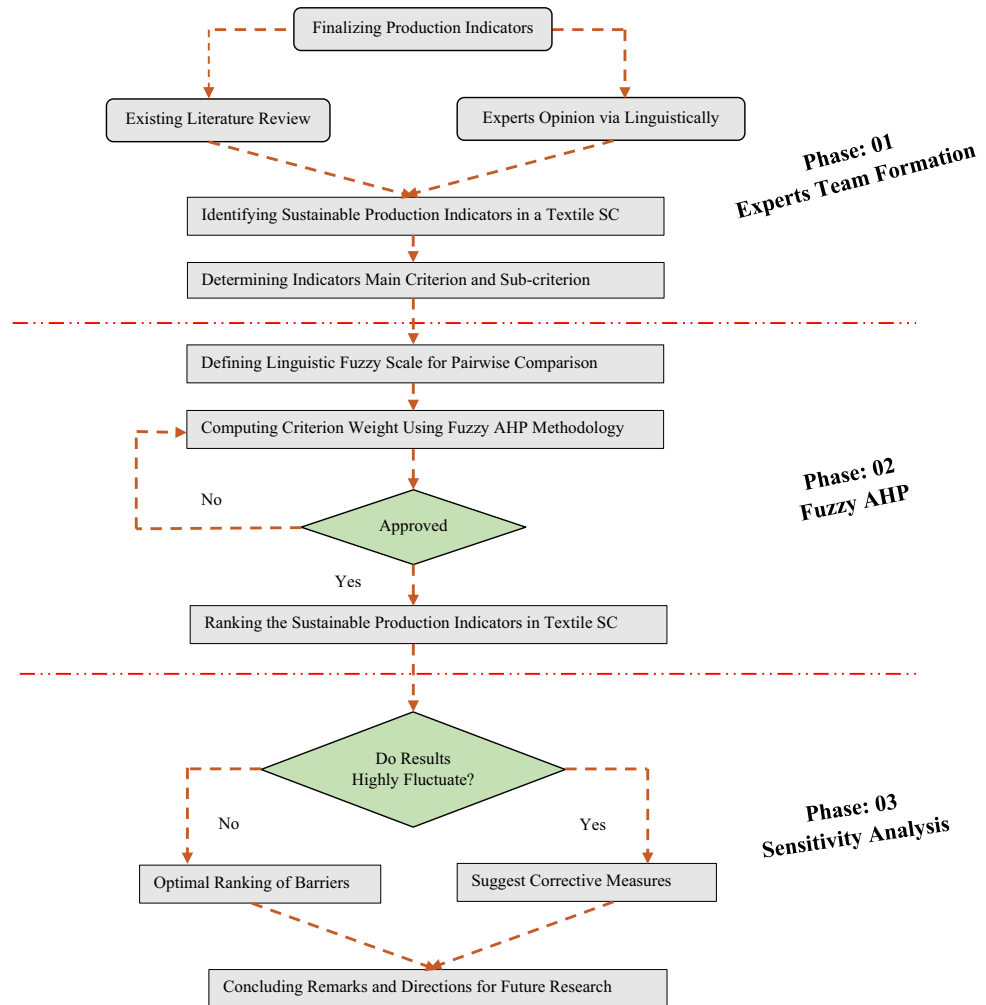
3. Proposed methodology

For accomplishing the objectives of present study, the authors conducted an extensive review of literature initially on sustainable operations and production practices and arranged multiple time panel discussions with academic as well as industrial experts. The inputs received from the concerned respondents regarding TESCO-based sustainable dimensions which were further used as main criterion in this study. This research investigates the key sustainable dimensions based on technical (T), ecological (E), socio-economic (S), core competencies (C) and operational (O) considerations to prioritize the (SPIs). The procedural phases of proposed fuzzy AHP model to prioritize the indicators in this study are sketched in [Figure 1](#). The present research utilized the knowledge of experts from five textile and apparel-based organization and two academicians as well from the relevant fields or disciplines. A hierarchical methodology is applied for identifying and prioritizing the key indicators of sustainable production in a textile supply chain. Nowadays, textile industries in Pakistan are considering the significance of production parameters and process improvement for gaining a competitive advantage. However, the evaluation and development of checklist of production indicators in a supply chain is a core issue, which needs to be addressed prior developing business strategies.

3.1. Fuzzy AHP

The Saaty's traditional AHP method was extended by fuzzy AHP through integration with fuzzy logic based on fuzzy set theory. The fuzzy AHP method used fuzzy evaluation scales for determination of the level of importance of the variables in the multi-attributed decision making

Figure 1. Proposed research model for sustainable production indicators in a textile supply chain.



problems. The fuzzy AHP technique was used to determine the priority weight of the list of factors. Fuzzy AHP is an approach to multi-criteria decision making where functional values are given based on a mathematical representation of possible pairwise comparisons of alternative decisions or outcomes. The benefit of fuzzy AHP is to arrange multiple criterion decisions into a single phrase that reflects the relationship between objectives, criteria, sub-criteria, and options. The criteria refer to the upper category groups, while the sub-categories refer to the lower category groups that defy these criteria. Using this approach, internal responses from researchers and fuzzy AHP participants can be reduced. In this study, fuzzy AHP framework structures and surveys were developed based on the results of the literature, qualitative studies, and experts inputs. In the survey tool, the scores for each pair-wise comparison matrices are evaluated. Scale 1 represents the pair's lowest score or the same weight, while Scale 5 represents the highest score compared to the pair. The recruitment of fuzzy AHP respondents was decided by face-to-face meetings and telephone calls with key decision-makers and experienced employees of selected textile companies in the study areas. In multi-criteria-based problems, a fuzzy pairwise comparison matrix can be constructed using experts inputs taking linguistic triangular fuzzy numbers. These linguistic expressions were further converted into numerical number or crisp number by performing arithmetic operations. The fuzzy logic tackle with multi-criteria decision-making (MCDM) problems under uncertain environments by applying numerous types of criterion. The criterion applied in this research have its basic fundamentals, numerical values, and intensity of weight vectors. In real-life industrial problems, it is quite complex to assess and

compute human judgment subjectively rather objectively. To cope up with this uncertainty and ambiguity, the researchers strongly proposed MCDM methods to solve industrial issues in multiple ways.

The fuzzy AHP mainly consists of 4 phases which are: (1) unlocking the key indicators (2) developing an hierarchy-based prioritization model for achieving sustainability, (3) developing questionnaire for collecting data form concerned experts, and (4) calculating normalized weights vector for all selected indicators categories. After the formulation of pairwise comparison matrix, the most important test which is known as consistency test, can be applied to check the consistency among the criterion to proceed further. The following two steps to compute the consistency ratio (CR).

- (1) Calculate the intensity of criterion weights and λ_{Max} for all matrix having n number of order
- (2) Calculate the consistency index (CI) for all matrix having n number of order by using below formula:

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

After getting CI values, the consistency ratio (CR) is can be computed using the below-mentioned formula:

$$CR = CI / RI \quad (2)$$

Due to uncertain environment and behavioral issues the inputs received from experts is not consistent sometimes using fuzzy AHP method because human judgment is not always consistent. In order to cope up with this problematic situation, the consistency ratio is used as a parameter to check the accuracy and consistency level among criterion values. If the value of (CR) is less or equal to 10%, then the variables are consistent. If the (CR) is greater than 10%, then the matrix is inconsistent and it needs to be revised with the subjective judgmental approach. The inputs received in the form of fuzziness can be to calculate the importance of the one criterion over other criteria using triangular fuzzy numbers in qualitative form. After taking consideration of these fuzzy numbers, a fuzzy pairwise comparison matrix is then formulated for every criterion and sub-criterion. These pairwise comparison matrices are used for the calculation of each major and sub-criterion weight vector. The intensity level of judgment for formulating the pairwise comparison matrix can be evaluated through the scale of optimism value l which calculated considering the experts inputs. For instance, if the value of index of optimism is greater than l then it indicates the higher degree of optimism and vice versa. The index of optimism is a linear convex combination and has been defined mathematically using α cut operation on triangular fuzzy number, in the Equation (3) (Lee et al., 2013).

$$\tilde{a}_{ij}^{\alpha} = \mu a_{ij}^{\alpha} + (1 - \mu) a_{ji}^{\alpha} \text{ where } 0 < \mu \leq 1 \quad (3)$$

4. Practical application

The developed model has been structured for sustainable evaluation and ranking of production indicators in a textile firms in a comprehensive way. The proposed model was developed in such a way that it can be used for the evaluation of multiple number of indicators. This section dealt with an empirical study, which was conducted to demonstrate the practical application of the proposed model. As this research is applying fuzzy tool, therefore, it was strongly suggested to include seven experts from the relevant fields of academia and industry in the decision-making process to reduce the chances of individual biasness. The target population considered in this research intend to enhance their major contribution towards the sustainability aspects i.e. technical, ecological, socio-economic, core competencies and operational performances. For this purpose, the operations and logistics managers were assumed various types of challenges in

development of production indicators under sustainable supply chain environment. For the proper implementation of proposed model a set of data was collected in terms of experts inputs for hierarchical model to assess the sustainability dimensions of production system in a textile-related firms.

4.1. Developing the hierarchy and instrument for collecting data required for indicators analysis

The present problem based on hierarchal structure which divides four major levels: (Level 1) unlocking or exploring the sustainable production indicators in a textile supply chain (Level 2), the five major identified indicators (Level 3) determine 25 sub-indicators (Level 4) analyze the ranking of indicators using fuzzy AHP. The proposed research flow based on different phases of fuzzy AHP model to prioritize the indicators is given in Figure 1. The leveling division of the addressed problem is provided in Figure 2.

4.2. Establishing the weights vectors of SPIs and determining ranks

The establishment of fuzzy pairwise comparison matrices were taken place through inputs of experts for both the five major and subcategory indicators using an intensity scale for relativeness provided in Table 2. The experts were requested to provide the values in fuzzy linguistic form using triangulation method. After considering and compiling the inputs, the triangular linguistics variables were converted to a fuzzy judgmental matrix. In this way, the fuzzy pairwise judgment matrix for major indicators were generated (see Table 3). The fuzzy pairwise judgment matrix for sub-indicators categories were

Figure 2. Decision hierarchy for prioritization of indicators in production.

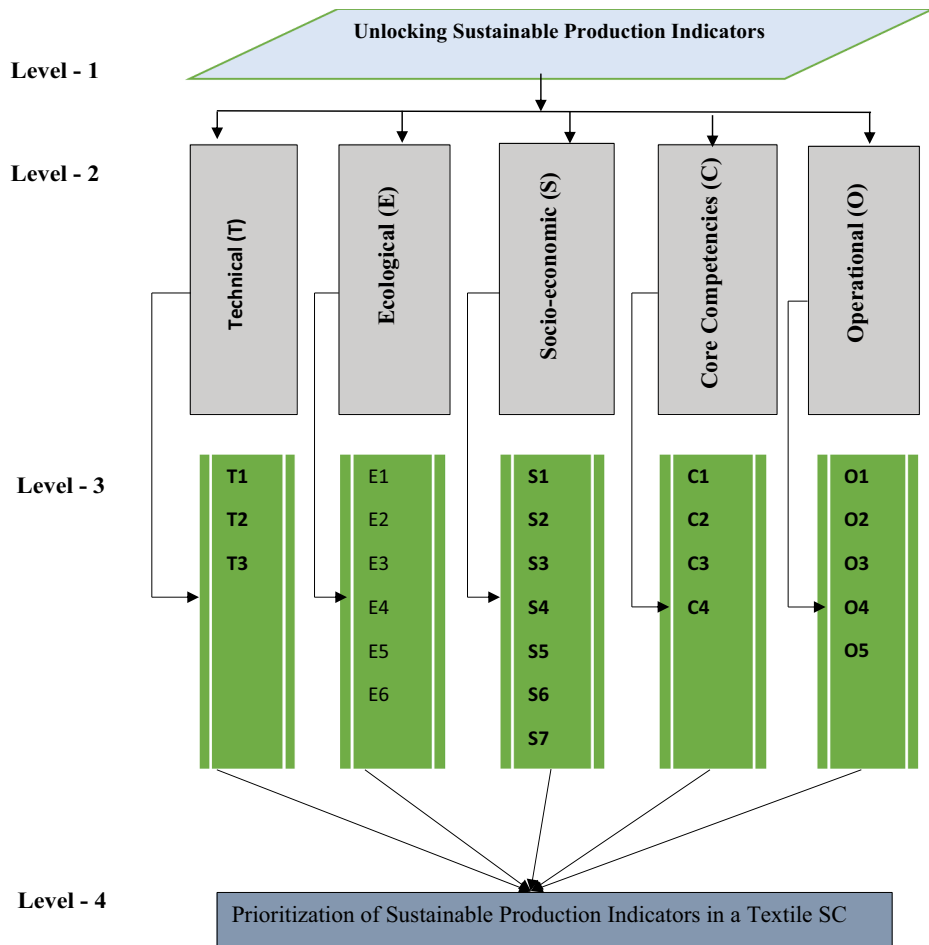


Table 2. The fuzzy scale used for construction of pairwise comparison matrix of major and sub-major criterion

| Level of intensity | Linguistic variables | Triangular fuzzy numbers | Reciprocal of TFNs |
|--------------------|--------------------------|--------------------------|-----------------------|
| 1 | Equally important | (0,1,3) | (0.33, 1, 0) |
| 2 | Equally to moderately | (1,2,4) | (0.25, 0.5,1) |
| 3 | Moderate important | (1,3,5) | (0.2, 0.33, 1) |
| 4 | Moderately to strong | (2,4,6) | (0.166, 0.25, 0.5) |
| 5 | Strong important | (3,5,7) | (0.142, 0.2, 0.33) |
| 6 | Strongly to very strong | (4,6,8) | (0.125, 0.166,0.25) |
| 7 | Very strong important | (5,7,9) | (0.111, 0.142, 0.2) |
| 8 | Very strong to extremely | (6,8,10) | (0.1, 0.125, 0.166) |
| 9 | Extreme important | (7,9,11) | (0.090, 0.111, 0.142) |

Table 3. Fuzzy pairwise comparison matrix of the major dimensions or criterion used in SPIs

| | T | E | S | C | O |
|---|-------|------|------|------|---|
| T | 1 | 3 | 2 | 6 | 3 |
| E | 0.33 | 1 | 3 | 3 | 5 |
| S | 0.5 | 0.33 | 1 | 4 | 3 |
| C | 0.166 | 0.33 | 0.25 | 1 | 3 |
| O | 0.33 | 0.2 | 0.33 | 0.33 | 1 |

Table 4. Fuzzy pairwise comparison matrix of the sub-criteria with respect to technical SPIs

| | T1 | T2 | T3 |
|----|-----|-------|----|
| T1 | 1 | 2 | 5 |
| T2 | 0.5 | 1 | 6 |
| T3 | 0.2 | 0.166 | 1 |

Table 5. Fuzzy pairwise comparison matrix of the sub-criteria with respect to the ecological SPIs

| | E1 | E2 | E3 | E4 | E5 | E6 |
|----|-------|------|-----|------|-----|----|
| E1 | 1 | 3 | 3 | 7 | 6 | 7 |
| E2 | 0.33 | 1 | 3 | 5 | 3 | 3 |
| E3 | 0.33 | 0.33 | 1 | 2 | 2 | 2 |
| E4 | 0.14 | 0.2 | 0.5 | 1 | 2 | 3 |
| E5 | 0.166 | 0.33 | 0.5 | 0.5 | 1 | 2 |
| E6 | 0.14 | 0.33 | 0.5 | 0.33 | 0.5 | 1 |

generated (see Tables 4–8) The sustainable production indicators weights vectors were created relevant to each major category indicators and sub-category indicators (see Table 9).

5. Discussion of findings

The present multi-attribute decision-making problems highlighted the current scenario of textile industries regarding sustainability aspects, which were technical, ecological, socio-economic, core competencies, and operational factors. The panel of experts include both from academia and

Table 6. Fuzzy pairwise comparison matrix of the sub-criteria with respect to the socio-economic SPIs

| | S1 | S2 | S3 | S4 | S5 | S6 | S7 |
|----|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| S1 | 1 | 3 | 2 | 3 | 5 | 7 | 7 |
| S2 | 0.33 | 1 | 2 | 3 | 5 | 6 | 3 |
| S3 | 0.5 | 0.5 | 1 | 3 | 6 | 3 | 2 |
| S4 | 0.33 | 0.33 | 0.33 | 1 | 5 | 3 | 3 |
| S5 | 0.2 | 0.2 | 0.166 | 0.2 | 1 | 2 | 2 |
| S6 | 0.14 | 0.166 | 0.33 | 0.33 | 0.5 | 1 | 2 |
| S7 | 0.14 | 0.33 | 0.5 | 0.33 | 0.5 | 0.5 | 1 |

Table 7. Fuzzy pairwise comparison matrix of the sub-criteria with respect to core competencies SPIs

| | C1 | C2 | C3 | C4 |
|----|-----------|-----------|-----------|-----------|
| C1 | 1 | 5 | 7 | 7 |
| C2 | 0.2 | 1 | 3 | 3 |
| C3 | 0.14 | 0.33 | 1 | 2 |
| C4 | 0.14 | 0.33 | 0.5 | 1 |

Table 8. Fuzzy pairwise comparison matrix of the sub-criteria with respect to the operational SPIs

| | O1 | O2 | O3 | O4 | O5 |
|----|-----------|-----------|-----------|-----------|-----------|
| O1 | 1 | 3 | 2 | 3 | 3 |
| O2 | 0.33 | 1 | 2 | 5 | 2 |
| O3 | 0.116 | 0.5 | 1 | 2 | 2 |
| O4 | 0.5 | 0.2 | 0.5 | 1 | 2 |
| O5 | 0.33 | 0.5 | 0.5 | 0.5 | 1 |

industry, i.e., one manager spinning, one knitting manager, one dyeing and finishing manager, one apparel manufacturing and garments, one director operations, and two associate professors from the relevant fields having more than 10 years' experience. This research identified, 25 indicators through existing literature review as well as from the consultation with industrial experts. This research is divided into four hierarchical levels to deal with the proposed problem. At the first level of hierarchy, the purpose of problem identified as "ranking the SPIs in a supply chain". The second level considers the major dimensions of indicators whereas on third level, sub-indicators are considered, forth level discuss the level of priority of indicators of hierarchy. As previously discussed in detail, initially, the experts were requested to create fuzzy pair-wise comparisons of five major dimension of sustainability and 25 sub-indicators by applying qualitative inputs. The consistency ratio (CR) values were calculated to check the level of consistency among all matrices which should be less than 0.1. After checking the consistency among variables, final weights values were obtained. The findings depict that technical indicator has a significant impact on decision-making process of a textile sector. The technical indicators are followed by ecological indicator, socio-economic indicator, core competencies indicators, and finally, operational indicator have less impact. Referring to the technical indicators sub-aspects, consumers' interest in the design strategies, renewable energy conservation were important in the sustainable production aspects.

The sensitivity analysis was conducted to analyze the ratings and fluctuations of key indicators by changing their weights vectors (Nazam et al., 2020). Previously, various researchers applied

Table 9. Weight assessment of major and sub-dimensions and final ranking of Indicator

| Major sustain ability dimensions | Main criterion weight | Sub-criteria Notations | Consistency Ratio (CR) | Relative weights using AHP | Global weight using AHP | Ranking |
|----------------------------------|-----------------------|------------------------|------------------------|----------------------------|-------------------------|---------|
| Technical (T) | 0.4040 | T1 | 0.0827 | 0.5499 | 0.2222 | 1 |
| | | T2 | | 0.3681 | 0.1487 | 2 |
| | | T3 | | 0.0820 | 0.0331 | 8 |
| Ecological (E) | 0.2717 | E1 | 0.0864 | 0.4544 | 0.1234 | 3 |
| | | E2 | | 0.2300 | 0.0625 | 5 |
| | | E3 | | 0.1194 | 0.0324 | 9 |
| | | E4 | | 0.0809 | 0.0220 | 12 |
| | | E5 | | 0.0671 | 0.0182 | 14 |
| | | E6 | | 0.0483 | 0.0131 | 17 |
| Socio-economic (S) | 0.1816 | S1 | 0.0988 | 0.3530 | 0.0641 | 4 |
| | | S2 | | 0.2232 | 0.0405 | 7 |
| | | S3 | | 0.1705 | 0.0310 | 10 |
| | | S4 | | 0.1140 | 0.0207 | 13 |
| | | S5 | | 0.0504 | 0.0091 | 18 |
| | | S6 | | 0.0453 | 0.0082 | 19 |
| | | S7 | | 0.0435 | 0.0079 | 20 |
| Core competencies (C) | 0.0837 | C1 | 0.0484 | 0.6533 | 0.0547 | 6 |
| | | C2 | | 0.1913 | 0.0160 | 15 |
| | | C3 | | 0.0910 | 0.0076 | 22 |
| | | C4 | | 0.0644 | 0.0054 | 25 |
| Operational (O) | 0.0590 | O1 | 0.0946 | 0.3976 | 0.0235 | 11 |
| | | O2 | | 0.2611 | 0.0154 | 16 |
| | | O3 | | 0.1337 | 0.0079 | 21 |
| | | O4 | | 0.1130 | 0.0067 | 23 |
| | | O5 | | 0.0946 | 0.0056 | 24 |

sensitivity analysis to confirm feasibility among the frameworks developed; therefore, for the current case scenario fluctuation in the numerical experts' inputs are taken while considering this analysis. In main indicators categories, the "technical indicator" is most prioritized indicators and ecological indicators is the second highest indicators and socio-economic, core competencies and operational indicators are third, four; it dictates that a slight change in the value of weight of these indicators can be impacted the rest of the indicators potentially. Therefore, the results depicts that technical indicators weight values are changed from 0.4040 (MB) to (0.4040*0.9 = 0.3636, 0.4040*0.8 = 0.3232, 0.4040*0.7 = 0.2828, 0.4040*0.6 = 0.2424, 0.4040*0.5 = 0.2020, 0.4040*0.4 = 0.1616, 0.4040*0.3 = 0.1212, 0.4040*0.2 = 0.0808 and 0.4040*0.1 = 0.0404, values). It has been noticed that slight changes can be seen in other indicators after changing the weights values (see Table 10). The significant fluctuation is seen in the ranking level of "ecological indicators, socio-economic indicators, core competencies, and operational indicators, respectively," category (see Table 11). The changes among the ranking results of sub-indicators are also drawn in Figure 3.

Table 10. Indicators values when changing technical SPIs values

| Main Indicators | Normal Weight | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 |
|-------------------|---------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Technical | 0.4040 | 0.3636 | 0.3232 | 0.2828 | 0.2424 | 0.2020 | 0.1616 | 0.1212 | 0.0808 | 0.0404 |
| Ecological | 0.2717 | 0.2827 | 0.2941 | 0.3060 | 0.3183 | 0.3312 | 0.3446 | 0.3585 | 0.3730 | 0.3881 |
| Socio-economic | 0.1816 | 0.1889 | 0.1966 | 0.2045 | 0.2128 | 0.2214 | 0.2303 | 0.2396 | 0.2493 | 0.2594 |
| Core competencies | 0.0837 | 0.0870 | 0.0905 | 0.0942 | 0.0980 | 0.1020 | 0.1061 | 0.1104 | 0.1148 | 0.1195 |
| Operational | 0.0590 | 0.0614 | 0.0639 | 0.0665 | 0.0692 | 0.0720 | 0.0749 | 0.0779 | 0.0810 | 0.0843 |

6. Managerial and theoretical implications

6.1. Managerial implications

While developing the checklist of SPIs, it is not an easy task for the management to implement all indicators determined in a shorter time period. For this purpose, the management needs to indicate the key indicators that have the highest priority among indicators to adopt in a production process. The findings of the results depict that technical indicator found as on top-ranked indicator, therefore, they management of the textile firms should pay more attention on technical issues. Additionally, the management should have to take a positive sense about sophisticated technological equipment's. The management should have the ability to select the efficient and most suitable technology for running the normal routine operations of the firms. The good management can expedite the adoption process of indicators by taking an effective possible ways. Therefore, managers can fix the technical issues in the organizational environment. If the management will be successful to implement SPIs strategy in their organizational system, then it would be beneficial to achieve sustainable organizational goals. The implantation of SPIs would be fruitful to enhance sustainable production, cleaner technologies and logistics, and physical distribution system of textile firms.

6.2. Theoretical and global implications

This research study explored and ranked major critical success factors or indicators in the Pakistani textile industries. The findings of this study would be helpful to the domestic and international beneficiaries to adopt SPIs in their industries by advancing the level of supply chain management. Recently international buyers are putting pressure on the Pakistani textile industries to adopt SPIs in the textile production process to improve technical, ecological, socio-economic, core competencies and operational aspects. The present study would be helpful for the industrial managers in improving production management practices in the textile supply chains. On the basis of this research, the new research framework can be developed for multiple sectors like, automotive industry, the pharmaceutical industry, chemicals, and the plastic industry, to evaluate major indicators as per their specific requirements.

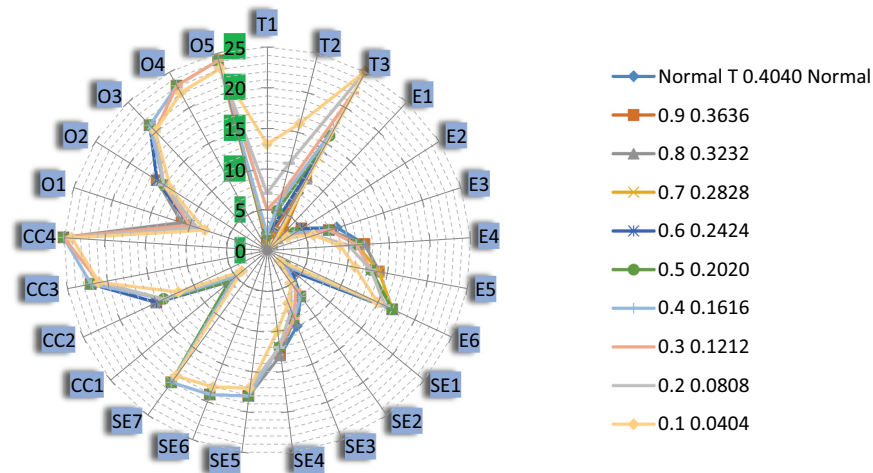
7. Conclusions, limitations, and future research avenues

This research study presents a model for sustainable production indicators for the textile manufacturing firms. An attempt has been made to include five dimensions for evaluation of sustainability of operations and production process of textile firms. The detailed list of SPIs for textile industries was determined through the review of literature and further these incorporated in the proposed model taking the parameters of textile industries. The priority weight vector of indicators were calculated and used to rank. The findings depict that technical indicator have significant impact on decision-making process of

Table 11. Sensitivity analysis of sub-barriers with “SO” barrier weight changes from (0.4040*0.9 ... 0.4040*0.1)

| | T = 0.4040 Normal | T = 0.3636 | T = 0.3232 | T = 0.2828 | T = 0.2424 | T = 0.2020 | T = 0.1616 | T = 0.1212 | T = 0.0808 | T = 0.0404 |
|-----|----------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| T1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 5 | 7 | 13 |
| T2 | 2 | 2 | 3 | 3 | 3 | 5 | 6 | 7 | 11 | 16 |
| T3 | 8 | 10 | 10 | 13 | 14 | 16 | 17 | 22 | 25 | 25 |
| E1 | 3 | 3 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 |
| E2 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 3 | 3 | 3 |
| E3 | 9 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 6 | 6 |
| E4 | 12 | 12 | 12 | 11 | 11 | 11 | 11 | 11 | 10 | 9 |
| E5 | 14 | 14 | 14 | 14 | 13 | 13 | 13 | 13 | 13 | 11 |
| E6 | 17 | 17 | 17 | 17 | 17 | 17 | 16 | 16 | 16 | 15 |
| SE1 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 2 | 2 | 2 |
| SE2 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 6 | 5 | 5 |
| SE3 | 10 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 8 | 7 |
| SE4 | 13 | 13 | 13 | 12 | 12 | 12 | 12 | 12 | 12 | 10 |
| SE5 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 17 | 17 | 17 |
| SE6 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 18 | 18 | 18 |
| SE7 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 19 | 19 | 19 |
| CC1 | 6 | 6 | 6 | 6 | 6 | 6 | 5 | 4 | 4 | 4 |
| CC2 | 15 | 15 | 15 | 15 | 15 | 14 | 14 | 14 | 14 | 12 |
| CC3 | 22 | 22 | 22 | 22 | 22 | 22 | 22 | 21 | 21 | 21 |
| CC4 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 24 | 24 |
| O1 | 11 | 11 | 11 | 10 | 10 | 10 | 10 | 10 | 9 | 8 |
| O2 | 16 | 16 | 16 | 16 | 16 | 15 | 15 | 15 | 15 | 14 |
| O3 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 20 | 20 | 20 |
| O4 | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 22 | 22 |
| O5 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 23 | 23 |

Figure 3. Results of sensitivity analysis for technical indicators (T).



a textile sector. The technical indicators are followed by ecological indicator, socio-economic indicator, core competencies indicators, and finally operational indicator have the less impact. Referring to the technical indicators sub-aspects, consumers' interest in the design strategies, renewable energy conservation were important in the sustainable production aspects.

Despite the contributions of this research, the present study has some limitations or shortcomings as well. In this research, we proposed a research model based on fuzzy AHP for sustainable production indicators in a textile supply chain. This model determined five major categories and 25 sub-indicators categories to rank the SPIs in a supply chain scenario. There are a lot of indicators which vary from culture to culture and geography to geography, which are not identified and categorized. In the future, more research can be taken for the identification and prioritization of sustainable indicators for textile industries. On the basis of this research, the new research framework can be developed for multiple sectors like, automotive industry, the pharmaceutical industry, chemicals, and the plastic industry, to evaluate major indicators as per their specific requirements.

Funding

The authors received no direct funding for this research.

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Citation information

Cite this article as: Unlocking the Sustainable Production Indicators: A Novel TESCO based Fuzzy AHP Approach, Muhammad Hashim, Muhammad Nazam, Muhammad Abrar, Zahid Hussain, Muhammad Nazim & Rizwan Shabbir, *Cogent Business & Management* (2021), 8: 1870807.

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