Prioritization of Environmental Uncertainty and Manufacturing Flexibility for Labor-Intensive Industry: A Case Study on Ready-Made Garment Industries in Bangladesh

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Abstract: Manufacturing flexibility is a widely accepted manufacturing strategy for mitigating the negative impacts of environmental uncertainty on firm performance and is also a required strategic attribute to acclimatize mass customization and agile manufacturing. Manufacturing flexibility has been adequately studied for technology-intensive industries but remains inadequately addressed for labor-intensive industries. In this study, a framework is proposed for sorting the relevant manufacturing flexibility types for the relevant environmental uncertainty types as an initial step towards implementing manufacturing flexibility in labor-intensive industries. This study considered the RMG (ready-made garment) industries in Bangladesh, which are mostly labor-intensive, as a case. Different types of manufacturing flexibility and environmental uncertainty were identified through a deductive approach from the existing literature and theory. Then, final sorting was conducted through a focus group discussion using the analytical hierarchy process (AHP) and decision making trial and evaluation laboratory (DEMATEL) techniques. This study revealed that demand, competitor, supplier, and technology uncertainty were ranked sequentially from first to fourth. This study also revealed that demand and competitor uncertainty would be the first-line focus, and supplier uncertainty the second-line focus, of decision makers. Similarly, new product, volume, workforce, and modification flexibility were ranked sequentially from first to fourth, and these would be considered first-line focuses by decision makers. This study also showed that all types of environmental uncertainties had an internal effect (one type affects another type within the types of environmental uncertainty). Internal effects among the different types of manufacturing flexibility were also identified. This study contributes to the theory of manufacturing flexibility for labor-intensive industries and will help decision makers gradually implement manufacturing flexibility based on their capacity and goal.

Keywords: manufacturing flexibility; environmental uncertainty; focus group discussion; analytical hierarchy process; decision making trial and evaluation laboratory; labor-intensive industry; ready-made garment industries

1. Introduction

With the progress of time and technology, human beings are progressing towards economic advancement and subsequently facing incremental environmental uncertainty (EU) in their businesses. Manufacturing systems have also been upgraded to the next level of paradigm due to EU: for example, mass production to mass customization, and lean manufacturing to agile manufacturing. This upgrading has also emphasized the
requirement of manufacturing flexibility. In the literature, manufacturing flexibility (MF) is widely suggested as a means to cope with EU for improving firm performance. Initially, MF was described as an attribute of flexible manufacturing systems (FMSs). Later, in the 1980s, the concept of MF was introduced independently for greater responsiveness to changes in production technologies, products, and markets in response to the need for mass customization [1]. At present, MF is described as the capacity to quickly respond to customer demand [2], where the system accommodates the internal and external changes and continues to produce a mix of various products in various volumes without compromising performance [3], as well as potentially reducing the lead time [4] to satisfy the customer. Similarly, supply chain flexibility is an additional interesting topic for researchers. Thomé et al. (2014) addressed the difference between these two concepts: “supply chain flexibility” is a broad concept that incorporates flexibility across multiple tiers within the supply chain, while “manufacturing flexibility” refers to the flexibility of individual firms [5]. MF is considered a fundamental element of supply chain flexibility [6].

The literature has shown that MF is a multidimensional and complex concept [7–9]. However, no universal categorization of MF can be found, since different scholars classified MF differently. Early conceptual studies on MF [10–13] advised that MF and EU be studied more extensively regarding the implementation of MF. Following this advice, a number of researchers conducted a number of studies on the implementation of MF. Among these studies, some [14–16] considered multiple types of industries, while a few considered [17,18] similarities within one type of industry. Researchers also suggested that studies on similar types of industries in a specific context would be more pragmatic [17,19]. Therefore, the selection of relevant EU and MF types for similar types of industries in a specific context is very important for initiating study on the implementation of MF. Researchers stressed this issue for high-tech industries (such as printed circuit board plants and the automotive industry) in the context of developed economies. However, this issue is not well addressed for labor-intensive industries, especially in developing economies. Moreover, the existing EU types and required types of MF are not similar for labor-intensive and high-tech industries due to the specific operational attributes of these industries. Labor-intensive industries are operationalized mainly with manual labor and simple machinery, while high-tech industries are operationalized mainly with technology, a skilled workforce, and modern automated machinery. To implement MF, the selection of relevant EU and MF types is the first step. Therefore, there is a need for selection of the relevant EU and MF types before initiating the implementation of MF in labor-intensive industries in developing economies.

The purpose of this study was to propose and implement a framework to sort out relevant MF and EU types in a labor-intensive industry. Following researchers’ suggestions for similar types of industries in a specific context, this study focused on RMG (ready-made garment) industries in Bangladesh, which are mostly labor-intensive industries in a developing economy. First, this study explored different types of EU and MF from the existing literature. Then, prioritizations from among the existing EU types and the relevant MF types were conducted. This study is an initial step towards implementing manufacturing flexibility in a labor-intensive industry, where the relevant EU and MF types were sorted scientifically from among numerous types of EU and MF.

This paper is structured as follows: After the introduction, Section 2 presents a literature review on types of environmental uncertainty and manufacturing flexibility, and the prioritization of multiple types of environmental uncertainty and manufacturing flexibility. Section 3 presents an overview of the ready-made garment industry in Bangladesh as a case of a labor-intensive industry. Section 4 describes the study framework, and Section 5 presents an empirical data analysis to sort out and prioritize the relevant EU and MF types so that decision makers can choose the prioritized EU types and MF types step by step and thereby implement them. This study provides a discussion in Section 6. Section 7 presents the conclusion with possible further extensions of the study.
2. Literature Review

2.1. Environmental Uncertainty (EU)

EU can be described as the unpredictable issues that arise from groups (such as customers, suppliers, market competition, technological changes, the firm itself, and government regulations) that make up the business environment of a unit. EU impedes the profitability of a firm and growth [20]. EU is broadly classified into two types: (i) internal uncertainties which occur within an organization and include manpower changes, machine breakdown, queuing delays, material shortages, variable task times, rejects and reworks, and resource acquisitions; and (ii) external uncertainties which include changes/fluctuations in competitor activities, technologies, macroeconomic policies, social and political uncertainty, product prices, and market demand [21]. Different scholars have also classified EU in various ways. Some examples are given below:

- Gerwin (1993) classified basic EU into seven types: (1) kind of product acceptance in the market, (2) product life cycle duration, (3) specific product specifications, (4) aggregate demand of the product, (5) machine downtime, (6) specifications of material, and (7) changes in the above six types [12].
- Ansoff et al. (2018) uncovered environmental challenges in broader aspects, namely, a shifting product market, developing nations, inadequate management capabilities, external sociopolitical issues, and disruptive technology [22].
- Ruchi Mishra (2021) focused on five types of environmental uncertainties: demand uncertainty (DU), supplier uncertainty (SU), competitor uncertainty (CU), technological uncertainty (TU), macro-environmental uncertainty (MEU) [23].
- In the context of the supply chain, Das and Abdel-Malek (2003) focused on four types of supply chain uncertainty, such as product mix, sales quantities, order delivery time, and design changes [24].
- Vaart et al. (2004) showed that volume, product mix, and lead time are the types of uncertainty for the integration of buyers and suppliers [25].

Moreover, in the literature, it was found that there were a number of different types of EU focused on by scholars, and Table 1 shows some of those.

| SL | Environmental Uncertainty | Source | Similar Term and Source | Frequency of Study |
|----|---------------------------|--------|-------------------------|--------------------|
| 1  | Supplier uncertainty      | [17,26–30] | Material price uncertainty [31]  
Supply volume uncertainty [28,32]  
Supply mix uncertainty [28,32]  
Supply delivery uncertainty [32]  
Supply new product design uncertainty [28]  
Supply product modification uncertainty [28] | 6 + 8 = 14 |
| 2  | Demand uncertainty        | [17,27,33–37] | Uncertainties such as fluctuating requirements [38]  
Demand variability pattern (volume, mix) [39] | 7 + 2 = 9 |
| 3  | Technological uncertainty | [26,29,33,35,36,40] | Future technical development [38]  
Product technology uncertainty [17] | 6 + 2 = 8 |
| 4  | Internal uncertainty      | [26] | Machine downtime [26]  
Departmental coordination problem [26]  
Resource acquisition and distributor problems [26]  
Workforce factor [26]  
Process uncertainty [27] | 1 + 5 = 6 |
| 5  | Competitor uncertainty    | [17,26,29,36] | 4 |
| 6  | Customer uncertainty      | [26,29] | 2 |
Table 1. Cont.

| SL  | Environmental Uncertainty                  | Source               | Similar Term and Source       | Frequency of Study |
|-----|-------------------------------------------|----------------------|-------------------------------|--------------------|
| 7   | Financial resource endeavor               | [41]                 | Resource-constrained [42]     | 1 + 1 = 2          |
| 8   | Sourcing uncertainty                       | [30]                 |                               | 1                  |
| 9   | Government regulations                     | [26]                 |                               | 1                  |
| 10  | Macroeconomic fluctuation                  | [26]                 |                               | 1                  |
| 11  | Macro-environment uncertainty              | [29]                 |                               | 1                  |
| 12  | Delivery uncertainty                       | [26]                 |                               | 1                  |
| 13  | Commercial uncertainty                     | [43]                 |                               | 1                  |
| 14  | Earnings uncertainty                       | [44]                 |                               | 1                  |

Table 1 shows that supplier uncertainty, demand uncertainty, technological uncertainty, internal uncertainty, and competitor uncertainty are the most frequently highlighted uncertainties by researchers.

2.2. Manufacturing Flexibility (MF)

Initially, MF was described as an attribute of flexible manufacturing systems, which are production systems that consist of a number of automated machine tools such as robots, computers, automated material handling and storage systems, and, in some cases, numerically controlled machine tools, where parts are processed and assembled for producing the final product [45].

Researchers classify this multidimensional issue in various ways and from different points of view.

From a hierarchical point of view:

- Browne (1984) classified eight types of flexibility under three levels (basic, system, and aggregate levels) [46];
- Slack (1987 and 1988) classified seven types within the resource and system levels [47,48];
- Dooner (1991) classified five types within the production, design, and base levels [49];
- Koste (1999) classified ten types of flexibility belonging to the individual resource, shop floor, plant, functional, and strategic business levels [50];
- Narashiman (1999) classified 11 types within the basic, tactical, and strategic levels [51];
- Sawhney (2006) classified 11 types within the input, process, and output levels [52].

From a strategic perspective:

- D’Souza (2000) classified MF as externally driven flexibility types (volume and variety) and internally driven flexibility types (process and material handling flexibility) [53];
- Oke (2005) classified MF as first-order (new product, mix, volume, and delivery flexibility) and lower-order (routing, component, material, and machine flexibility) [54];
- Javid (2019) classified MF as basic flexibility (operation, material handling, and machine), potential flexibility (product, process, volume, expansion, and routing), and actual flexibility (market, production, and program) [7];
- Jain (2013) classified MF as action-oriented: adaptive, proactive, or a combination [9];
- Zhang, Vonderembse, and Lim (2003) classified MF as manufacturing competencies (machine, labor, material handling, and routing flexibilities), and manufacturing capabilities (volume flexibility, and mix flexibility) [55].

Due to the different approaches, a number of MF types are available in the literature. Researchers also identified a number of MF types, such as 20 different terms [3], 70 items [56], and at least 50 items [57], in the existing literature, and this number continues to increase [58].
Moreover, MF was studied by researchers according to their contextual interests, focusing on different MF types. Table 2 shows some examples of different types of manufacturing flexibility and supply chain flexibility from the literature.

**Table 2.** Types related to manufacturing flexibility and supply chain flexibility.

| SL | Manufacturing Flexibility | Source | Similar Term and Source | Frequency of Study |
|----|---------------------------|--------|-------------------------|--------------------|
| 1  | New product flexibility   | [17,29–31,36,59–61] | Flexibility in design platforms [38] | 8 + 5 = 13 |
|    |                           |        | Design flexibility [62]  |                    |
|    |                           |        | MF in product styling [63]|                    |
|    |                           |        | Product innovation [64]  |                    |
|    |                           |        | Pleasure-oriented product development with manufacturing flexibility [65] | |
| 2  | Volume flexibility        | [17,19,26,30,41,60,66–69] | | 10 |
| 3  | Labor flexibility         | [26,30,36,40,44,60,66,70] | Worker flexibility [42] | 8 + 1 = 9 |
| 4  | Process flexibility       | [26,30,39,41,64,67–69] | Process system design flexibility [71] | 8 + 1 = 9 |
| 5  | Product mix flexibility   | [26,29,61] | Mix flexibility [17,19,36,37,60,67] | 3 + 6 = 9 |
| 6  | Product flexibility       | [26,30,41,68,69,72,73] | | 7 |
| 7  | Machine flexibility       | [26,30,36,60,68–70] | | 7 |
| 8  | Supply chain flexibility  | [60,74–76] | Supply chain responsiveness [33] | 4 + 3 = 7 |
|    |                           |        | Product-dominant supply chain flexibility [15] | |
|    |                           |        | Service-dominant supply chain flexibility [15] | |
| 9  | Logistics flexibility     | [39,60] | Distribution flexibility [39] | 2 + 4 = 6 |
|    |                           |        | Physical distribution flexibility [72] | |
|    |                           |        | Alternative logistics flexibility [66] | |
|    |                           |        | Distribution/logistics flexibility [77] | |
| 10 | Routing flexibility       | [26,30,41,60,68,70] | | 6 |
| 11 | Modification flexibility  | [19,60,61,67,70] | | 5 |
| 12 | Supplier flexibility      | [30,32,39,66,77] | | 5 |
| 13 | Material handling flexibility | [26,30,60,70] | | 4 |
| 14 | Strategic flexibility     | [76,78–80] | | 4 |
| 15 | Delivery flexibility      | [19,26,29,30] | | 4 |
| 16 | Operations flexibility    | [30,60,70] | Operational flexibility [80] | 1 + 3 = 4 |
| 17 | Expansion flexibility     | [30,41,60] | | 3 |
| 18 | Sourcing flexibility      | [30,66] | | 2 |
| 19 | Marketing flexibility     | [26,59] | | 2 |
| 20 | Trans-shipment flexibility | [20,66] | | 2 |
| 21 | Subcontracting flexibility | [66] | | 1 |
| 22 | Storage flexibility       | [66] | | 1 |
| 23 | Flexible information system | [66] | | 1 |
| 24 | Flexible information visibility | [66] | | 1 |
Table 2. Cont.

| SL | Manufacturing Flexibility                          | Source                          | Similar Term and Source                                                                 | Frequency of Study |
|----|---------------------------------------------------|---------------------------------|-----------------------------------------------------------------------------------------|--------------------|
| 25 | Supplier collaboration flexibility                 | [66]                            |                                                                                         | 1                  |
| 26 | Inter-organizational relationship flexibility      | [66]                            |                                                                                         | 1                  |
| 27 | Organizational environment flexibility             | [66]                            |                                                                                         | 1                  |
| 28 | Meta flexibility                                  | [41]                            |                                                                                         | 1                  |
| 29 | Assembler flexibility                             | [39]                            |                                                                                         | 1                  |
| 30 | Access flexibility                                | [30]                            |                                                                                         | 1                  |
| 31 | Investment flexibility                            | [34]                            |                                                                                         | 1                  |
| 32 | Procurement flexibility                           | [39]                            |                                                                                         | 1                  |
| 33 | Continuous improvement flexibility                | [30]                            |                                                                                         | 1                  |
| 34 | Throughput time reduction flexibility             | [30]                            |                                                                                         | 1                  |
| 35 | Ramp-up time reduction flexibility                | [30]                            |                                                                                         | 1                  |
| 36 | Decoupling point flexibility                      | [30]                            |                                                                                         | 1                  |
| 37 | Postponement flexibility                          | [30]                            |                                                                                         | 1                  |
| 38 | Demand flexibility                                | [26]                            |                                                                                         | 1                  |
| 39 | Demand management flexibility                     | [72]                            |                                                                                         | 1                  |
| 40 | Labor market flexibility                          | [81]                            | Employment or numerical, work process or functional, and wage flexibility [81]         | 1                  |
| 41 | Flexibility in resource allocation                | [43]                            |                                                                                         | 1                  |
| 42 | Structural flexibility in production              | [80]                            |                                                                                         | 1                  |
| 43 | Planning flexibility                              | [82]                            |                                                                                         | 1                  |
| 44 | Customer-oriented flexibility                     | [74]                            |                                                                                         | 1                  |
| 45 | Green product flexibility                         | [70]                            |                                                                                         | 1                  |
| 46 | Energy flexibility                                | [70]                            |                                                                                         | 1                  |
| 47 | Pollution flexibility                             | [70]                            |                                                                                         | 1                  |
| 48 | Recycling flexibility                             | [70]                            |                                                                                         | 1                  |
| 49 | Biodegradability flexibility                      | [70]                            |                                                                                         | 1                  |
| 50 | Changeover flexibility                            | [19]                            |                                                                                         | 1                  |
| 51 | Material flexibility                              | [69]                            |                                                                                         | 1                  |

Table 2 shows that many types of manufacturing flexibility and supply chain flexibility were focused on in the literature. Table 2 also shows the frequency of each type of flexibility. These numerous types of MF puzzle researchers and decision makers in selecting the
appropriate type of MF for their context. Javid (2019) also reported that due to the numerous types of flexibility, there is an existence of inharmony in defining the types of MF [7]. For example, some terms were used interchangeably [9], and the same type of flexibility was referred to by different names [54]. The meanings of MF types also vary from context to context [52,83]. Meanings were also influenced by operating policies and management practices [50], management structure, corporate culture, facility layout, process technology, and information systems [84–86]. For these above reasons, a careful selection of MF types has been suggested by researchers to cope with the environmental changes of the target context [87,88].

2.3. Prioritization of EU and MF

The types of EU faced by manufacturers vary from industry to industry. Therefore, the appropriate types of required MF also vary for different industries [4]. In 2017, Mishra [29] conducted a study on a fashion apparel firm in India, mainly considering external EU: consumer uncertainty, competitor uncertainty, supplier uncertainty, technological uncertainty, and macro-environment uncertainty. Here, four types of MF: volume, product mix, new product, and delivery flexibility, were prioritized through multi-criteria decision making (MCDM) methods (integrated AHP (analytical hierarchy process) and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution)) [29]. This study was limited to four types of MF. Moreover, these four types of MF were suggested for the high-tech industry (printed circuit board assembler) of developed economies (the United States, Europe, and Japan). Meanwhile, the fashion industry is one of the labor-intensive industries, and the studied firm was in a developing economy (the northern part of India). In the case of EU, the study was focused on external uncertainties, ignoring internal uncertainty such as manufacturing uncertainty. A study on a food company in Taiwan applied quality function deployment (QFD) to prioritize the required MF and the existing EU. The study also applied grey relational analysis (GRA) to analyze the relationship between EU and MF and determined dependency among the MF types. This study was focused on consumers’ product demands, suppliers’ problems, competitors’ strategic change, macroeconomic fluctuation, technology capability, global infectious diseases, equipment failure, and the workforce factor in EU. This study also found that product flexibility was the most important, and other important flexibilities were, sequentially, production, market, volume, labor, expansion, machine, and material handling flexibility [21]. The selected EU and MF types were also different from other studies, which might be due to the industry type and context. In 2021, Ruchi Mishra ranked volume, delivery, new product, and product mix sequentially first to fourth to deal with multiple types of EU for an Indian auto-air conditioning manufacturing firm, using the hybrid fuzzy AHP-TOPSIS method [23]. Using fuzzy DEMATEL (decision making trial and evaluation laboratory), another study showed that volume, manufacturing, supplier collaboration, and supplier flexibility were highly influential in the supply chain flexibility of an Indian automotive supply chain under the sales promotional scheme environment [66].

Therefore, the selection of EU and MF types for their prioritization should be based on the context and industry. As these prioritizations are a multi-criterion decision making (MCDM) problem and depend on experts’ opinions, MCDM methods should be selected and implemented according to experts’ capacities. This study implemented the AHP and DEMATEL after discussion with experts. The AHP was first developed and explained by Saaty in 1990 [89]. The AHP allows decision makers to explain the goal and problem in a hierarchical model, and to rank the factors according to their importance. On the other hand, the DEMATEL technique was first developed by the Geneva Research Centre of the Battelle Memorial Institute to visualize a complicated structure by causal relationships through matrices and digraphs [90]. The DEMATEL technique prioritizes the critical influential factors of any complex system and groups those factors according to interactive relationships.
3. Overview of RMG Industry of Bangladesh

The ready-made garment (RMG) industry sources raw materials (finished fabric and accessories) according to the requirements of contracts. The core processes of the RMG industry are fabric spreading and cutting, cut panel sewing, finishing and packing the complete garments, and delivery according to the contract. All processes are highly labor-intensive rather than relying on technology [91]. The industry uses only information technologies and some software packages. Very little automation is used in this industry [91]. Usually, the industry is buyer-driven [92] and supplier-dependent [93] in its supply chain.

In Bangladesh, the RMG industry started its journey in the late 1970s, and currently, the industry is 50 years old. Due to its substantial growth, it contributed 83% (USD 27,949.19 million) of total export earnings of the country [94], employing around 4 million people in 4621 garments industries and 1500 backward and forward linkage industries, in 2019–2020 [95]. The Apparel Story, January to March 2020 [94], published that 79% of total export items were only five basic products: t-shirts, trousers, shirts, jackets, and sweaters, mostly made of cotton which is a very narrow product mix for the industry to be competitive in the global market, and hence the growth of exports is inconsistent and declining compared to its competitors. In the March 2020 Newsletter on exports [95], BTMA reported that a few manufacturers are now looking to enrich the product mix range, and in recent years, some products such as suits/blazers, lingerie, active wear and outerwear, high-end denim, value-added basic items, and non-cotton items have been added to expand the exports. In 2019, the World Trade Organization (WTO) [96] reported that Bangladesh held the third position as a clothing exporter from 2016 up to 2019 after China and the European Union, followed by Vietnam, India, Turkey, Hong Kong, the UK, Indonesia, and Cambodia, which make up the top ten clothing exporters accordingly. Bangladesh is producing low-end products with an acceptable quality at the cheapest rate in large volumes with the help of a cheap workforce. However, the latest challenger of Bangladesh, Vietnam, is producing more value-oriented products with the favor of strong textiles and a more educated workforce [95]. At present, the industry is looking for initiatives to ensure long-term growth by catering to the need of branded fashion segments and penetrating higher market segments [94]. In this connection, the industry needs to satisfy the international buyers of branded fashion and retailers and be competitive in the market. According to global fashion executives, published in The State of Fashion 2019 by BoF and McKinsey & Company, dealing with volatility, uncertainty, shifts in the global economy, competition from online and omni-channels, etc., represented the top challenges or environmental uncertainties for three consecutive years, from 2017 to 2019, which negatively impacted firms’ performance such as sales and profitability growth [97]. The second-line challenges were supply chain and value chain improvement and digitalization, offline retailing pressure, and decreasing foot traffic and targets to achieve transparency and sustainability, according to global fashion executives [97]. Therefore, the RMG industry of Bangladesh is facing the above-mentioned EU as the industry is driven by international buyers of branded fashion and retailers, and it has to satisfy them and be competitive in the market.

In its inception, RMG production was carried out only through a craft production system to meet the local demand only, or, in some cases, individuals’ demand only. With the advancement of the production system, this industry shifted to mass production system and is moving toward mass customization system [98]. Very few remarkable studies are available on the RMG industry for EU and MF issues. However, all have some shortcomings. For example, Mishra’s [29] study was limited to a province and a few MF types; Tomastik’s [99] study was limited to the sewing process; and Palominos’s [68] study was limited to the level of MF. Moreover, these studies followed the categorization of EU and MF types which were suggested for the high-tech industry of developed economies. A study also showed that among 22 strategies, MF is the most important and influential to manage the impacts of the COVID-19 pandemic for an RMG industry in Bangladesh [100].
In these circumstances, a specific categorization of EU and MF types is needed for the RMG industries of Bangladesh.

4. Methodology

This study was conducted following the framework shown in Figure 1.

The study framework used both deductive (sourcing from the relevant existing theory and literature) and inductive (through focus group discussion (FGD)) approaches. Here, EU and MF types were identified (Tables 1 and 2, respectively) from a large body of literature, with 72 articles being selected. These articles were selected from Scopus and Google Scholar indexed journals. Several keywords such as “manufacturing flexibility”, “environmental uncertainty”, “firm performance”, “garment”, “apparel”, “clothing”, and “fashion” were used to search for these articles up to 2021.

For the inductive approach, a focus group discussion (FGD) panel was formed with five academics (named AA to AE) and ten industrial experts (named IA to IL) from the relevant field. The professional experience of the industry experts was linked to different RMG industries. Academic professors contributed to shortening the list of EU and MF types along with the industry experts and also contributed to clarifying the queries of the industry experts along with the researchers. They also guided the researchers during the discussion sessions. Table 3 shows a brief overview of the FGD panel.
3. Detail of the FGD panel.

| Identity | Experience Range | Highest Education | Designation         |
|----------|------------------|-------------------|---------------------|
| 1        | AA               | More than 20 years| Ph.D               | Professor          |
| 2        | AB               | More than 20 years| Ph.D               | Professor          |
| 3        | AC               | More than 20 years| Ph.D               | Professor          |
| 4        | AD               | 10–20 years       | Ph.D               | Associate Professor|
| 5        | AE               | 10–20 years       | M.Sc.              | Associate Professor|
| 6        | IA               | More than 20 years| B.Sc.              | Top management     |
| 7        | IB               | More than 20 years| B.Sc.              | Top management     |
| 8        | IC               | 10–20 years       | M.Sc.              | Top management     |
| 9        | ID               | 10–20 years       | MBA                | Top management     |
| 10       | IE               | 10–20 years       | B.Sc.              | Top management     |
| 11       | IF               | 10–20 years       | B.Sc.              | Top management     |
| 12       | IG               | 10–20 years       | B.Sc.              | Top management     |
| 13       | IH               | 5–10 years        | B.Sc.              | Mid management     |
| 14       | II               | 5–10 years        | B.Sc.              | Mid management     |
| 15       | IJ               | 5–10 years        | B.Sc.              | Mid management     |

Identified EU and MF types (Tables 1 and 2, respectively) were presented to the members of the FGD panel. After this, through discussion among the members of the FGD panel, the relevant EU and MF types were selected and sorted. The sorted EU and MF types were listed as initial sorted EU and MF types. Moreover, during this sorting process, the experts were requested to focus on the following:

- Gerwin’s (1993) conceptual framework (shown in Figure 2) on EU, MF, and firm performance.
- Frequency of EU and MF types in Tables 1 and 2, respectively.
- Scenarios and requirements of the RMG industry according to their experience.

![Figure 2. Modified Gerwin's model [12].](image)

Once the EU and MF types were initially sorted, the AHP and DEMATEL techniques were implemented with the help of the industry expert panel (through interviews) from the FGD group. The consistency of the experts’ opinion was tested using the AHP technique. Finally, the prioritization was concluded according to the AHP and DEMATEL outputs through the FGD for both EU and MF types.

5. Data Analysis

The initial sorted EU and MF types are presented in Tables 4 and 5, respectively.

Tables 4 and 5 show that 7 types of EU and 10 types of MF were found to be relevant for RMG industries according to the academics and industrial experts of the FGD panel (all 15 members). The definitions of the 7 types of EU and 10 types of MF that were adopted by the authors of this study are presented in Appendix A. To implement the AHP and DEMATEL, the opinions of industry experts were considered to be more realistic and precise than academician opinions. Before the collection of opinions, both the AHP and
DEMATEL techniques and the initial sorted EU (Table 4) and MF types (Table 5) were discussed comprehensively with the ten industrial experts. The opinions were collected using two different types of pairwise comparison scale. Tables 6 and 7 show the scales for the AHP and DEMATEL, respectively, with illustrations. Opinions on EU and MF types were collected separately.

Table 4. Initial sorted relevant EU types for RMG industries.

| SL | Environmental Uncertainty                  | Remarks                             | Abbreviation |
|----|--------------------------------------------|-------------------------------------|--------------|
| 1  | Demand uncertainty                          |                                     | DU           |
| 2  | Competitor uncertainty                      |                                     | CU           |
| 3  | Technological uncertainty                   |                                     | TU           |
| 4  | Supplier uncertainty                        |                                     | SU           |
| 5  | Manufacturing uncertainty                   | Renamed from internal uncertainty from Table 1 | MU           |
| 6  | Uncertainty from government and public view | Renamed from government regulations | UGP          |
| 7  | Macro-environment uncertainty               | Merged from macroeconomic fluctuation and macro-environment uncertainty | MEU          |

Table 5. Initial sorted relevant MF types for RMG industries.

| SL | Manufacturing Flexibility                  | Remarks                             | Abbreviation |
|----|--------------------------------------------|-------------------------------------|--------------|
| 1  | New product flexibility                    |                                     | NPF          |
| 2  | Modification flexibility                    |                                     | MoF          |
| 3  | Volume flexibility                          |                                     | VF           |
| 4  | Product mix flexibility                     | Merged from product mix flexibility and product flexibility | PMF          |
| 5  | Process flexibility                         |                                     | PF           |
| 6  | Workforce flexibility                       | Renamed from labor flexibility      | WfF          |
| 7  | Machine flexibility                         |                                     | MaF          |
| 8  | Routing flexibility                         |                                     | RF           |
| 9  | Material handling flexibility               |                                     | MHF          |
| 10 | Expansion flexibility                       |                                     | EF           |

Table 6 shows the scale for pairwise comparisons among factors X, Y, Z, and W with an example. Opinions should be given for non-shaded cells only. For example, if factor X has extreme importance over Y, and W has strong importance over X, the corresponding values in the matrix would be 9 and 1/5, respectively. The diagonal cells show that the factors are equally important by themselves, and hence the corresponding values in the matrix would be 1. On the other hand, the shaded cells contain values for an inverse comparison.

Table 7 shows the scale for pairwise comparisons among factors X, Y, Z, and W with an example. Opinions should be given for non-shaded cells, either as a letter grade or an integer value. For example, if the factor X has a medium influence and a very high influence on Y and Z, respectively, the corresponding letter grade in the matrix would be M and VH. Similarly, if factor W has a low influence on X, the corresponding letter grade in the matrix would be L. The shaded cells show that factors are not influenced by themselves and hence have the letter grade N.
Table 6. Illustration of the pairwise comparison scale for the AHP.

| Scale                        | Pairwise Comparison Matrix |
|------------------------------|----------------------------|
| Equal importance = 1        | X  | Y  | Z  | W  |
| Moderate importance = 3     | X  | 1  | 9  | 1/5|
| Strong importance = 5       | Y  | 1/9| 1  |
| Very strong importance = 7  | Z  | 5  |    | 1  |
| Extreme importance = 9      | W  | 5  |    | 1  |

For a compromise between the above values = 2, 4, 6, and 8.

Table 7. Illustration of the pairwise comparison scale for DEMATEL.

| Intensity of Influence | Letter Grade | Integer Value | Pairwise Comparison Matrix |
|------------------------|--------------|---------------|---------------------------|
| No influence           | N            | 0             | X  | Y  | Z  | W  |
| Low influence          | L            | 1             | X  | N  | VH | X  | 0  | 2  | 4  |
| Medium influence       | M            | 2             | Y  | N  |    |    | 0  | 0  |
| High influence         | H            | 3             | Z  | N  |    |    |    | 0  |
| Very high influence    | VH           | 4             | W  | L  | N  | W  | 1  | 0  |

The AHP technique has an option to check the consistency of individual expert opinions, whereas the DEMATEL technique does not have this option, which is a limitation. To overcome this limitation of DEMATEL, when a consistent matrix of opinion in the AHP was found from an individual expert, his/her opinion was collected for the DEMATEL technique. After the implementation of the AHP and DEMATEL, the final prioritization of the EU and MF types was conducted through another discussion with the FGD panel. FGD panel recommendations were also tabulated along with the final prioritization.

5.1. AHP Implementation for Prioritizing

5.1.1. EU Types

The goal and hierarchy are shown in Figure 3 for prioritizing the EU types. Seven types of EU (Table 4) were included in the hierarchy.

![Figure 3. Goal and hierarchy of the EU types.](image)

Pairwise comparison matrices among the seven EU types were collected from the ten industry experts of the FGD panel for the AHP following Table 6. For example, the implementation of the AHP in a pairwise comparison matrix from one expert (IA) is detailed in Tables 8 and 9.
Table 8. Determination of the weight and rank of EU types by expert “IA”.

| EU Types | Pairwise Comparison Matrix | Normalized Matrix | Weight Matrix | Rank |
|----------|-----------------------------|-------------------|--------------|------|
| DU       | 1.00 4.00 6.00 4.00 3.00 8.00 7.00 DU | 0.44 0.66 0.40 0.36 0.26 0.24 0.24 0.37 | 1 |
| CU       | 0.25 1.00 4.00 5.00 3.00 7.00 7.00 CU | 0.11 0.16 0.27 0.45 0.26 0.21 0.24 0.24 | 2 |
| TU       | 0.17 0.25 1.00 0.33 2.00 6.00 5.00 TU | 0.07 0.04 0.07 0.03 0.17 0.18 0.17 0.105 | 4 |
| SU       | 0.25 0.20 3.00 1.00 2.00 6.00 5.00 SU | 0.11 0.03 0.20 0.09 0.17 0.18 0.17 0.14 | 3 |
| MU       | 0.33 0.33 0.50 0.50 1.00 5.00 3.00 MU | 0.15 0.05 0.03 0.04 0.09 0.15 0.10 0.09 | 5 |
| UGP      | 0.13 0.14 0.17 0.17 0.20 1.00 1.00 UGP | 0.06 0.02 0.01 0.01 0.02 0.03 0.03 0.03 | 7 |
| MEU      | 0.14 0.14 0.20 0.20 0.33 1.00 1.00 MEU | 0.06 0.02 0.01 0.02 0.03 0.03 0.03 0.03 | 6 |

Table 9. Determination of the consistency of the pairwise comparison matrix on EU types by expert “IA”.

| EU Types | Weighted Sum Value | Weight | Weighted Sum Value/Weight | Consistency Check |
|----------|-------------------|--------|--------------------------|------------------|
| DU       | 3.20              | 0.37   | 8.64                     | λmax 7.77        |
| CU       | 2.10              | 0.24   | 8.65                     | CI 0.13          |
| TU       | 1.08              | 0.14   | 7.89                     | RI 1.32          |
| SU       | 0.64              | 0.09   | 7.22                     | CR 0.097 Consistent Matrix |
| MU       | 0.20              | 0.03   | 7.36                     |                 |
| UGP      | 0.22              | 0.03   | 7.38                     |                 |
| MEU      | 0.06              | 0.02   | 7.03                     |                 |

Here, λmax, CI, and RI are the usual notations for AHP computation.

Table 8 shows the pairwise comparison matrix obtained from an industrial expert (IA). This matrix was used to compute a normalized matrix, and a weight matrix according to the AHP computation. Then, the EU types were ranked according to their corresponding value in the weight matrix.

Table 9 shows the AHP computation for the consistency of the pairwise matrix obtained from expert IA. It shows that the CR (consistency ratio) was 0.097. As the CR was below 0.1, the obtained pairwise matrix was consistent.

Similarly, pairwise comparison matrices obtained from the nine other industry experts were computed for the AHP. The weight of the EU types by the ten industry experts and the CR (consistency ratio) of the corresponding pairwise comparison matrices are presented in Table 10. The average weights of each EU type were computed and hence ranked according to the order of their average weight. Table 10 also presents the average weight and rank of the EU types.

Table 10. Weight and rank of the EU types and the CR of the pairwise comparison matrices.

| EU Type | Weight of EU Types by Ten Industry Experts | Average Weight | Rank |
|---------|-------------------------------------------|----------------|------|
| DU      | 0.37 0.39 0.41 0.36 0.40 0.37 0.39 0.31 0.12 0.10 | 0.322 | 1 |
| CU      | 0.24 0.13 0.22 0.20 0.20 0.21 0.26 0.22 0.19 0.21 | 0.208 | 2 |
| TU      | 0.10 0.12 0.16 0.16 0.13 0.13 0.10 0.17 0.09 0.07 | 0.123 | 4 |
| SU      | 0.14 0.22 0.10 0.13 0.15 0.10 0.12 0.12 0.22 0.30 | 0.16 3 |
| MU      | 0.09 0.08 0.05 0.08 0.08 0.12 0.09 0.07 0.31 0.25 | 0.122 5 |
| UGP     | 0.03 0.03 0.04 0.03 0.03 0.04 0.03 0.06 0.04 0.04 | 0.037 6 |
Similarly, pairwise comparison matrices among the 10 MF types for the AHP were collected from the ten industry experts of the FGD panel following Table 5. The weight of the MF types and the CR of the corresponding matrices were determined and are presented in Table 11. The MF types were ranked according to the average weight of importance given by the industry experts and are shown sequentially in Table 12.

Table 11 shows that NPF was given the highest importance to expert. The CR values of all pairwise comparison matrices were below 0.1, and hence the obtained pairwise matrices from the individual industrial experts were consistent.

5.1.2. MF Types

The goal and hierarchy are shown in Figure 4 for prioritizing the MF types for implementing the AHP. Ten types of MF (Table 5) were included in the hierarchy.

Table 10 shows that, with the highest average weight, DU was ranked first and considered the most important among the EU types. CU, SU, TU, and MU were ranked as the second to fifth most important EU types, respectively. UGP and MEU may be considered as low-importance EU types due to their low weight for RMG industries in Bangladesh. This table also shows that all CRs (consistency ratios) of the corresponding pairwise matrices were below 0.1, and hence the obtained pairwise matrices from the individual industrial experts were consistent.

| EU Type | IA | IB | IC | ID | IE | IF | IG | IH | II | JJ | Average Weight | Rank |
|---------|----|----|----|----|----|----|----|----|----|----|----------------|------|
| MEU     | 0.03 | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.05 | 0.03 | 0.03 |   | 0.027          | 7    |
| CR      | 0.097 | 0.098 | 0.093 | 0.094 | 0.091 | 0.084 | 0.098 | 0.0996 | 0.078 | 0.074 |                   |      |

Table 11. Weight of the MF types and the CR of the pairwise comparison matrices.

| MF Types | IA | IB | IC | ID | IE | IF | IG | IH | II | JJ | Average Weight | Rank |
|----------|----|----|----|----|----|----|----|----|----|----|----------------|------|
| NPF      | 0.29 | 0.16 | 0.32 | 0.28 | 0.27 | 0.24 | 0.09 | 0.22 | 0.11 | 0.16 |                   |      |
| VF       | 0.17 | 0.28 | 0.21 | 0.19 | 0.14 | 0.18 | 0.10 | 0.15 | 0.17 | 0.12 |                   |      |
| PMF      | 0.08 | 0.10 | 0.12 | 0.14 | 0.13 | 0.18 | 0.12 | 0.13 | 0.11 | 0.15 |                   |      |
| PF       | 0.09 | 0.08 | 0.12 | 0.09 | 0.13 | 0.11 | 0.16 | 0.12 | 0.07 | 0.07 |                   |      |
| WfF      | 0.11 | 0.20 | 0.08 | 0.08 | 0.11 | 0.11 | 0.23 | 0.10 | 0.18 | 0.11 |                   |      |

Figure 4. Goal and hierarchy of the MF types.
### Table 11. Cont.

| MF Types | IA | IB | IC | ID | IE | IF | IG | IH | II | IJ |
|----------|----|----|----|----|----|----|----|----|----|----|
| MoF      | 0.10 | 0.07 | 0.06 | 0.08 | 0.11 | 0.10 | 0.18 | 0.09 | 0.24 | 0.25 |
| MaF      | 0.08 | 0.05 | 0.03 | 0.05 | 0.05 | 0.02 | 0.07 | 0.07 | 0.03 | 0.05 |
| RF       | 0.03 | 0.03 | 0.03 | 0.04 | 0.03 | 0.02 | 0.03 | 0.05 | 0.03 | 0.03 |
| EF       | 0.02 | 0.01 | 0.02 | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 |
| MHF      | 0.04 | 0.03 | 0.02 | 0.02 | 0.01 | 0.02 | 0.02 | 0.03 | 0.03 | 0.03 |
| CR       | 0.095 | 0.097 | 0.084 | 0.099 | 0.084 | 0.064 | 0.096 | 0.099 | 0.087 | 0.090 |

### Table 12. Prioritization of MF according to the average weight.

| MF Types | Average Weight | Rank |
|----------|----------------|------|
| NPF      | 0.214          | 1    |
| VF       | 0.171          | 2    |
| WfF      | 0.131          | 3    |
| MoF      | 0.128          | 4    |
| PMF      | 0.126          | 5    |
| PF       | 0.104          | 6    |
| MaF      | 0.050          | 7    |
| RF       | 0.032          | 8    |
| MHF      | 0.025          | 9    |
| EF       | 0.022          | 10   |

5.2. DEMATEL Implementation for Prioritizing

5.2.1. EU Types

Pairwise comparison matrices among the seven EU types were collected from the ten industry experts of the FGD panel for DEMATEL following Table 7. For example, a pairwise comparison matrix from one expert (IA) is shown in Table 13. The computation of DEMATEL is shown in Tables 14–17 and Figure 5.

### Table 13. Pairwise comparison matrix from expert “IA”.

| EU Types | Pairwise Comparison Matrix with Letter Grade | EU Types | Pairwise Comparison Matrix with Integer Value |
|----------|---------------------------------------------|----------|-------------------------------------------|
| DU       | N   | CU   | SU   | DU   | CU   | SU   | TU   | MU   | UGP  | MEU   | DU   | CU   | SU   | DU   | CU   | SU   | TU   | MU   | UGP  | MEU   |
| CU       | VH  | N    | VH   | VH   | VH   | L    | H    | DU   | 4    | 0    | 4    | 4    | 4    | 4    | 1    | 3    |
| SU       | L   | H    | N    | H    | H    | H    | L    | SU   | 1    | 3    | 0    | 3    | 3    | 3    | 3    | 1    |
| TU       | M   | H    | H    | N    | M    | L    | L    | TU   | 2    | 3    | 3    | 0    | 2    | 1    | 1    | 1    |
| MU       | L   | L    | L    | M    | N    | L    | L    | MU   | 1    | 1    | 1    | 2    | 0    | 1    | 1    | 1    |
| UGP      | M   | L    | L    | L    | N    | L    | N    | UGP  | 2    | 1    | 1    | 1    | 1    | 0    | 1    | 1    |
| MEU      | L   | M    | L    | L    | L    | N    | N    | MEU  | 1    | 2    | 1    | 1    | 1    | 1    | 1    | 0    |
Table 14. Initial direct relation matrix (average opinions of ten industry experts) and normalized direct relation matrix.

| EU Types | Initial Direct Relation Matrix, A | Normalized Direct Relation Matrix, Y |
|----------|-----------------------------------|--------------------------------------|
|          | DU      | CU      | SU      | TU      | MU      | UGP     | MEU |
| DU       | 0.00    | 3.64    | 3.45    | 3.27    | 2.64    | 1.45    | 2.27 |
| CU       | 3.27    | 0.00    | 3.36    | 2.09    | 1.91    | 1.82    | 2.27 |
| SU       | 2.27    | 2.73    | 0.00    | 1.82    | 2.73    | 1.91    | 1.18 |
| TU       | 2.18    | 2.36    | 2.09    | 0.00    | 1.64    | 1.27    | 1.55 |
| MU       | 2.18    | 2.09    | 1.55    | 1.45    | 0.00    | 1.55    | 1.45 |
| UGP      | 1.09    | 1.27    | 1.45    | 1.36    | 1.36    | 0.00    | 1.36 |
| MEU      | 1.36    | 1.36    | 1.27    | 1.45    | 1.36    | 0.91    | 0.00 |

| EU Types | DU      | CU      | SU      | TU      | MU      | UGP     | MEU |
|----------|-----------------------------------|--------------------------------------|
| DU       | 0.22    | 0.21    | 0.20    | 0.16    | 0.09    | 0.14    | MEU |
| CU       | 0.20    | 0.20    | 0.13    | 0.11    | 0.11    | 0.14    | MEU |
| SU       | 0.14    | 0.16    | 0.11    | 0.16    | 0.11    | 0.07    |
| TU       | 0.13    | 0.14    | 0.13    | 0.10    | 0.08    | 0.09    |
| MU       | 0.13    | 0.13    | 0.09    | 0.09    | 0.09    | 0.09    |
| UGP      | 0.07    | 0.08    | 0.08    | 0.08    | 0.08    |
| MEU      | 0.08    | 0.08    | 0.08    | 0.08    | 0.08    | 0.08    |

Table 15. (I-Y) matrix.

| EU Types | DU      | CU      | SU      | TU      | MU      | UGP     | MEU |
|----------|-----------------------------------|--------------------------------------|
| DU       | 1.00    | −0.22   | −0.21   | −0.20   | −0.16   | −0.09   | −0.14|
| CU       | −0.20   | 1.00    | −0.20   | −0.13   | −0.11   | −0.11   | −0.14|
| SU       | −0.14   | −0.16   | 1.00    | −0.11   | −0.11   | −0.11   | −0.07|
| TU       | −0.13   | −0.14   | −0.13   | 1.00    | −0.10   | −0.08   | −0.09|
| MU       | −0.13   | −0.13   | −0.09   | −0.09   | 1.00    | −0.09   | −0.09|
| UGP      | −0.07   | −0.08   | −0.09   | −0.08   | −0.08   | 1.00    | −0.08|
| MEU      | −0.08   | −0.08   | −0.08   | −0.09   | −0.08   | −0.05   | 1.00 |

Here, I = identity matrix.

Table 16. Inverse of (I-Y) and total relation matrix, T.

| EU Types | DU      | CU      | SU      | TU      | MU      | UGP     | MEU |
|----------|-----------------------------------|--------------------------------------|
| DU       | 1.39    | 0.59    | 0.58    | 0.52    | 0.50    | 0.36    | 0.43 |
| CU       | 0.51    | 1.37    | 0.53    | 0.43    | 0.43    | 0.35    | 0.40 |
| SU       | 0.42    | 0.46    | 1.32    | 0.37    | 0.42    | 0.32    | 0.31 |
| TU       | 0.38    | 0.41    | 0.40    | 1.25    | 0.34    | 0.27    | 0.30 |
| MU       | 0.36    | 0.38    | 0.35    | 0.31    | 1.23    | 0.26    | 0.28 |
| UGP      | 0.25    | 0.27    | 0.28    | 0.25    | 0.25    | 1.14    | 0.23 |
| MEU      | 0.26    | 0.28    | 0.27    | 0.25    | 0.25    | 0.19    | 1.15 |

| EU Types | DU      | CU      | SU      | TU      | MU      | UGP     | MEU |
|----------|-----------------------------------|--------------------------------------|
| DU       | 0.39    | 0.59    | 0.58    | 0.52    | 0.50    | 0.36    | 0.43 |
| CU       | 0.51    | 0.37    | 0.53    | 0.43    | 0.43    | 0.35    | 0.40 |
| SU       | 0.42    | 0.46    | 0.32    | 0.32    | 0.31    | 0.42    | 0.32 |
| TU       | 0.38    | 0.41    | 0.40    | 0.29    | 0.26    | 0.28    | 0.27 |
| MU       | 0.36    | 0.38    | 0.35    | 0.31    | 1.23    | 0.26    | 0.28 |
| UGP      | 0.25    | 0.27    | 0.28    | 0.25    | 0.25    | 1.14    | 0.23 |
| MEU      | 0.26    | 0.28    | 0.27    | 0.25    | 0.25    | 0.19    | 1.15 |

| EU Types | DU      | CU      | SU      | TU      | MU      | UGP     | MEU |
|----------|-----------------------------------|--------------------------------------|
| DU       | 0.36    | 0.59    | 0.58    | 0.52    | 0.50    | 0.36    | 0.43 |
| CU       | 0.51    | 0.37    | 0.53    | 0.43    | 0.43    | 0.35    | 0.40 |
| SU       | 0.42    | 0.46    | 0.32    | 0.32    | 0.31    | 0.42    | 0.32 |
| TU       | 0.38    | 0.41    | 0.40    | 0.29    | 0.26    | 0.28    | 0.27 |
| MU       | 0.36    | 0.38    | 0.35    | 0.31    | 1.23    | 0.26    | 0.28 |
| UGP      | 0.25    | 0.27    | 0.28    | 0.25    | 0.25    | 1.14    | 0.23 |
| MEU      | 0.26    | 0.28    | 0.27    | 0.25    | 0.25    | 0.19    | 1.15 |

Here, I = identity matrix.

Threshold value, alpha (α), average value of T matrix = 0.34.

Table 17. DEMATEL results for the EU types.

| EU Types | r (Row Sum Vector of Matrix T) | c (Column Sum Vector of Matrix T) | r + c (Influence) | Rank | r − c (Relation) | Group |
|----------|-------------------------------|-----------------------------------|-------------------|------|-----------------|-------|
| DU       | 3.36                          | 2.57                              | 5.93              | 1    | 0.80            | Cause |
| CU       | 3.01                          | 2.76                              | 5.77              | 2    | 0.25            | Cause |
| SU       | 2.62                          | 2.72                              | 5.33              | 3    | −0.10           | Effect|
Table 17. *Cont.*

| EU Types | r (Row Sum Vector of Matrix T) | c (Column Sum Vector of Matrix T) | r + c (Influence) | Rank | r − c (Relation) | Group |
|----------|---------------------------------|-----------------------------------|-------------------|------|-----------------|-------|
| TU       | 2.34                            | 2.37                              | 4.72              | 4    | −0.03           | Effect|
| MU       | 2.17                            | 2.41                              | 4.59              | 5    | −0.24           | Effect|
| UGP      | 1.65                            | 1.88                              | 3.53              | 7    | −0.23           | Effect|
| MEU      | 1.65                            | 2.10                              | 3.75              | 6    | −0.45           | Effect|

Figure 5. Interactive relationships of the EU types.

Table 17 shows that DU is the most influential EU with the highest influence value (5.93) and was ranked first. Other EU types were also ranked according to their influence \((r + c)\) values. This table also shows that DU and CU are in the cause group due to their positive relation \((r − c)\) values (0.80 and 0.25, respectively). These two EU types directly affect the others. SU, TU, MU, UGP, and MEU are in the effect group due to their negative relation \((r − c)\) values, and these are largely influenced by the others.

The interactive relationships of the EU types were obtained in the total relation matrix, \(T\), from Table 16. Considering the threshold value, 0.34 (average value of the \(T\) matrix), the interactive relationships of the EU types are shown in Figure 5.

Three types of interactive relationships are shown in Figure 5. DU is influenced by itself as the corresponding value of DU to DU is 0.39 (\(T\) matrix in Table 17), which is more than the threshold value, 0.34. CU is also influenced by itself. Again, DU and CU are mutually influenced, with the corresponding values of DU to CU and CU to DU being 0.59 and 0.51, respectively. MEU is only influenced by DU and CU, with the corresponding values of DU to MEU and CU to MEU being 0.43 and 0.40, respectively. Other relationships are also shown in Figure 5.

5.2.2. MF Types

Similarly, pairwise comparison matrices among the 10 MF types were collected from the ten industry experts of the FGD panel for DEMATEL following Table 7. The results of DEMATEL are shown below in Tables 18 and 19 and Figure 6.
Table 18. DEMATEL results for the MF types.

| MF Types | \( r + c \) (Influence) | Rank | \( r - c \) (Relation) | Group  |
|----------|--------------------------|------|------------------------|--------|
| NPF      | 7.87                     | 1    | 0.26                   | Cause  |
| VF       | 7.45                     | 2    | 0.43                   | Cause  |
| PMF      | 6.31                     | 5    | -0.65                  | Effect |
| PF       | 5.97                     | 6    | -0.13                  | Effect |
| WfF      | 7.03                     | 3    | 0.70                   | Cause  |
| MoF      | 6.79                     | 4    | 0.17                   | Cause  |
| MaF      | 5.72                     | 7    | -0.17                  | Effect |
| RF       | 5.69                     | 8    | -0.61                  | Effect |
| MHF      | 4.64                     | 9    | 0.09                   | Cause  |
| EF       | 4.28                     | 10   | -0.11                  | Effect |

Table 19. Total relation matrix, \( T \).

| MF  | NPF | VF  | PMF | PF  | WfF | MoF | MaF | RF  | MHF | EF  |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| NPF | 0.39| 0.47| 0.48| 0.44| 0.46| 0.41| 0.40| 0.44| 0.29| 0.29|
| VF  | 0.51| 0.35| 0.48| 0.38| 0.40| 0.45| 0.39| 0.38| 0.29| 0.31|
| PMF | 0.36| 0.34| 0.25| 0.29| 0.31| 0.30| 0.27| 0.28| 0.22| 0.22|
| PF  | 0.37| 0.35| 0.33| 0.22| 0.30| 0.32| 0.28| 0.32| 0.21| 0.21|
| WfF | 0.50| 0.44| 0.43| 0.40| 0.31| 0.44| 0.38| 0.40| 0.28| 0.27|
| MoF | 0.44| 0.41| 0.40| 0.34| 0.37| 0.29| 0.34| 0.37| 0.27| 0.23|
| MaF | 0.35| 0.33| 0.30| 0.29| 0.29| 0.31| 0.21| 0.29| 0.21| 0.19|
| RF  | 0.33| 0.30| 0.29| 0.24| 0.26| 0.30| 0.24| 0.20| 0.20| 0.18|
| MHF | 0.31| 0.26| 0.26| 0.25| 0.24| 0.27| 0.22| 0.25| 0.14| 0.18|
| EF  | 0.24| 0.26| 0.25| 0.20| 0.22| 0.22| 0.20| 0.22| 0.16| 0.12|

Threshold value, average value of \( T \) matrix = 0.31.

Figure 6. Interactive relationships of the MF types.
Table 18 shows the ranks of the MF types. It also shows that NPF, VF, WfF, MoF, and MHF are in the cause group and directly affect the others. PMF, PF, MaF, RF, and EF are in the effect group and are influenced by the others.

Considering the threshold value, 0.31 (average value of the T matrix, Table 19), the interactive relationships of the MF types are shown in Figure 6. This also shows three types of interactive relationships among the 10 MF types like Figure 5. Figure 6 shows that NPF, VF, and WfF are influenced by themselves. Among the other interactive relationships, NPF, VF, WfF, and MoF contribute most of the relationships.

5.3. Final Prioritization and Recommendations through FGD for EU and MF Types

The findings of the AHP and DEMATEL show the importance and influence of all relevant types of EU and MF in the system. However, it is very difficult to focus on all types of EU and MF at a time. To make the implementation of MF pragmatic, the initially selected 7 EU and 10 MF types were included in the first to fourth lines of choices through an FGD. This categorization will help decision makers take the appropriate initiative to implement different types of MF step by step. The priorities of the EU and MF types revealed almost similar rankings by both the AHP and DEMATEL techniques. These findings also guided the FGD panel for the final prioritization of the EU and MF types. Moreover, the FGD panel was also more focused on cause groups for both the EU and MF types, as these groups have a greater tendency to affect the whole system. Tables 20 and 21 show the final prioritization of the EU and MF types, respectively, along with the FGD recommendations for RMG industries. These tables also show the FGD opinions on prioritization for the RMG industry.

Table 20. Final prioritization and recommendations through the FGD for the EU types.

| SL | EU Types | FGD Priorities and Recommendations | FGD Opinions on Prioritization for RMG Industry |
|----|----------|-----------------------------------|-----------------------------------------------|
| 1  | DU       | First-line choice for both short- and long-term strategies | High priority and factor of the cause group. Unanticipated market demand and competition. |
| 2  | CU       | Second-line choice for both short- and long-term strategies | All raw materials are sourced from national and international suppliers. |
| 3  | SU       | Third-line choice for long-term strategies | The processes and products are neither high-technology-dependent nor oriented. |
| 4  | TU       | Fourth-line choice for long-term strategies | Simple machines, processes, and material handling systems. |
| 5  | MU       | Very low importance and long-term issue. |

Table 21. Final prioritization and recommendations through the FGD for the MF types.

| SL | MF Types | FGD Priorities and Recommendations | FGD Opinions on Prioritization for RMG Industry |
|----|----------|-----------------------------------|-----------------------------------------------|
| 1  | NPF      | First-line choice for both short- and long-term strategies | High priority and factor of the cause group. Requires a wide variety of products. |
| 2  | VF       | High priority and factor of the cause group. Requires a wide variety and a low volume of products. |
| 3  | WfF      | High priority and factor of the cause group. RMG industry is highly workforce-intensive. |
| 4  | MoF      | High priority and factor of the cause group. Requires a wide variety of products. |
| 5  | PMF      | Low importance and alternatively made up of the insights from NPF, VF, and MoF. |
| 6  | PF       | Low importance, and RMG industry is simple- and repetitive-process-oriented. |
### Table 21. Cont.

| SL | MF Types | FGD Priorities and Recommendations | FGD Opinions on Prioritization for RMG Industry |
|----|----------|-----------------------------------|-----------------------------------------------|
| 7  | MaF      | Third-line choice for long-term strategies | Very low importance, and machines of RMG industry carry out simple tasks. |
| 8  | RF       | Very low importance, and RMG industry follows repetitive processes. |
| 9  | MHF      | Very low importance, and RMG industry follows simple material handling processes that are not automated. |
| 10 | EF       | Fourth-line choice for long-term strategies | Low importance and long-term issue. |

Tables 20 and 21 show the first- to fourth-line choices along with the required strategies for both the EU and MF types. Implementation of all MF types at a time is not possible because it is a continuous process and requires gradual adaption. Therefore, decision makers can make their choice sequentially to implement the MF types according to their capacity and goal.

### 6. Discussion

The methodology of this study was focused on sorting out the relevant EU and MF types for a labor-intensive industry. To be more precise, a highly labor-intensive RMG industry in a specific context, Bangladesh, was studied. RMG industries of Bangladesh mainly produce basic products through mass production. However, the target market requires a wide variety of products with a low volume in a highly competitive environment. Therefore, decision makers of RMG industries are facing EU and should give importance to MF.

The AHP and DEMATEL techniques were used to prioritize the factors according to the importance and influence among the factors, respectively. The authors selected these two techniques because they fulfill the requirements of the study and the experts were comfortable with them. Here, researchers may also implement other similar types of MCDM techniques such as fuzzy AHP, fuzzy DEMATEL, TOPSIS, and fuzzy TOPOSIS, according to their preferences and considering experts’ capacity. The priorities of the EU and MF types revealed almost similar rankings by both the AHP and DEMATEL. These findings also guided the FGD panel in the final prioritization of the EU and MF types. The FGD panel was also more focused on cause groups for both the EU and MF types, as these groups have a greater tendency to affect the whole system.

As the RMG industry needs to cater to the highly competitive market with a wide variety of products with a low volume to achieve a strategic fit in the supply chain, NPF, VF, and MoF were highly prioritized with high importance and influence. This finding is similar to the findings of Mishra et al. from 2017 [29] on a fashion firm. Moreover, as the industry is highly labor-intensive, the experts also ranked workforce flexibility as third due to its high importance and influence. However, in 2017, Mishra et al. [29] did not include labor/workforce flexibility in their study. In the case of the EU types, the findings of this study are also similar to those of Mishra et al. from 2017. On the other hand, this study also suggested a categorization with the requirements of both short- and long-term strategies. This categorization will be a guideline for decision makers to choose MF types to cope with EU types step by step and implement them easily. Four MF types (NPF, VF, MoF, and WfF) were suggested as first-line choices which are very appropriate to cope with the first-line EU types (DU and CU) and even the second-line type (SU). PMF and PF as second-line choices, MaF, RF, and MHF as third-line choices, and EF as a fourth-line choice were recommended among the different types of MF. This study also recommended TU and MU as third-line choices and UGP and MEU as fourth-line choices among the different types of EU. Decision makers can deploy the MF sources to achieve their goals according to their choice of MF and capacity. For example, NPF can be developed by increasing R&D
(research and development) programs, VF by practicing modular sewing lines, MoF by increasing design capabilities, and WfF by growing a multi-skilled workforce.

This study was mostly dependent on the perception of the members of the FGD panel. Therefore, a relevant and appropriate FGD panel was very important for this study. The FGD panel had high potential considering its relevancy to the RMG industry. However, the relevant FGD panel and the implementation of MCDM techniques made the study more convenient in a scientific way.

This study directly shows the practical implications for the RMG industries of Bangladesh. The outcome of this study might be adaptable to any labor-intensive industry upon review. The scope of the deployed methodology is very wide, but a potential and relevant FGD panel should be ensured.

7. Conclusions

To fulfill the requirement of a wide variety and low volume of products with limited resources and tight constraints, manufacturing decision makers are puzzled when it comes to maintaining a high-quality firm performance. Manufacturing flexibility is a widely recognized approach for sustaining firm performance in the presence of environmental uncertainty. However, it is costly and very hard to focus on all EU and MF types at a single time for both researchers and decision makers. This study selected and categorized the relevant MF types to cope with the relevant EU types for a labor-intensive industry, in particular the RMG industries in Bangladesh. Therefore, decision makers may take their actions step by step following the final prioritization. This study may be considered as an initial step to implementing MF in RMG industries in Bangladesh. Besides this, this study contributes to the theory of manufacturing flexibility for labor-intensive industries and also provides a strategy to implement MF in labor-intensive industries. This study will be extended to find out the association between EU types and MF types for the same context through confirmatory factor analysis. Finally, particularly emphasizing the prioritized EU and MF types, a model will also be developed through structural equation modeling to implement MF in RMG industries in Bangladesh.

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Nomenclature

| Acronym | Description |
|---------|-------------|
| AHP     | Analytical hierarchy process |
| CI      | Consistency index |
| CR      | Consistency ratio |
| CU      | Competitor uncertainty |
| DEMATEL | Decision making trial and evaluation laboratory |
| DU      | Demand uncertainty |
| EF      | Expansion flexibility |
| EU      | Environmental uncertainty |
| FGD     | Focus group discussion |
| FMS     | Flexible manufacturing system |
Appendix A

The authors adopted the following definitions for environmental uncertainty and initially selected seven EU types:

| Uncertainty                                    | Definitions adopted by authors                                                                 |
|-----------------------------------------------|-------------------------------------------------------------------------------------------------|
| Environmental uncertainty                    | Environmental uncertainty arises when conditions are constantly changing within a business environment. |
| Demand uncertainty                            | Uncertainty arises due to changes from consumer/contract ends such as changes in product specification, volume, and lead time. |
| Competitor uncertainty                        | Uncertainty arises due to changes in the activities of competitors such as new product launch, promotions, and discounts. |
| Technological uncertainty                     | Uncertainty arises due to changes in the technology such as new technology and obsolete current technology. |
| Supplier uncertainty                          | Uncertainty arises due to changes from supplier ends such as changes in product quality, volume, and lead time. |
| Manufacturing uncertainty                     | Uncertainty arises due to unexpected breakdown and shutdown of partial or full manufacturing operations. |
| Uncertainty from government and public view    | Uncertainty arises due to changes in public views and government regulations such as green products and tax. |
| Macro-environmental uncertainty                | Uncertainty arises due to changes in the growth rate of the industry and the environmental consciousness of people. |

The authors adopted the following definitions for manufacturing flexibility and initially selected ten MF types:

| Flexibility                                    | Definitions adopted by authors                                                                 |
|-----------------------------------------------|-------------------------------------------------------------------------------------------------|
| Manufacturing flexibility                      | Manufacturing flexibility is referred to as the ability of a manufacturing system to successfully address the changes in environmental conditions. |
| New product flexibility                        | The ability of a manufacturing system to produce a new product with new specifications from the existing ones with minimum loss/penalty. |
Volume flexibility The ability to operate profitably at different product output levels. 
Product mix flexibility The ability to handle a range of products or variants with existing setups with minimum loss/penalty. 
Process flexibility The ability to complete several different tasks in the system using a variety of machines with minimum loss/penalty. 
Labor flexibility The ability to change the number of workers, tasks performed by workers, and responsibilities with minimum loss/penalty. 
Modification flexibility The ability of a manufacturing process to implement minor design changes in a given product with minimum loss/penalty. 
Machine flexibility The ability of the machine to switch operation without requiring major effort. 
Routing flexibility The ability to produce a part by alternative routes with minimum loss/penalty. 
Material handling flexibility The ability to move different materials efficiently for proper processing and positioning through the manufacturing facilities. 
Expansion flexibility The ability of a manufacturing system to increase its capacity and capability when needed.

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