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# Applying Integrated QFD-MCDM Approach to Strengthen Supply Chain Agility for Mitigating Sustainable Risks

Chih-Hung Hsu <sup>1</sup>, Ru-Yue Yu <sup>1</sup>, An-Yuan Chang <sup>2,\*</sup>, Wan-Ling Liu <sup>3,\*</sup> and An-Ching Sun <sup>1</sup>

<sup>1</sup> College of Transportation, Fujian University of Technology, Fuzhou 350118, China; chhsu886@gmail.com (C.-H.H.); yu\_ruyue@163.com (R.-Y.Y.); acs@fjut.edu.cn (A.-C.S.)

<sup>2</sup> Institute of Industrial Management, College of Management, National Formosa University, Yunlin 632, Taiwan

<sup>3</sup> Faculty of Economics and Business, University of Groningen, Nijenborgh 4, 9747 AG Groningen, The Netherlands

\* Correspondence: ayc@nfu.edu.tw (A.-Y.C.); w.l.liu@student.rug.nl (W.-L.L.)

**Abstract:** As the global economy develops and the complexity of supply chains increases, the effective mitigation of sustainable supply chain risks in electronics manufacturing has become important. While quality function deployment (QFD) has been successfully applied to many fields of multicriteria decision-making (MCDM), there is a lack of research on constructing a house-of-quality model that can be combined with MCDM for connecting supply chain agility with sustainable supply chain risks, especially in the field of electronics manufacturing. The objective of this study was to develop an integrated framework of QFD and MCDM and to devise an effective method to mitigate sustainable supply chain risks by improving supply chain agility. Such a method can help the multinational electronics manufacturing industry to develop stable and sustainable supply chains. In a multinational electronic manufacturing enterprise as an example, the results showed that the case enterprise work should focus on improving agility ‘production and sales capability’, ‘quick decision-making/strategic flexibility’, ‘electronic shipment of finished products to control shipment operations’, ‘supplier on-time delivery rates’ and ‘cost minimization’. Improving agility would help enhance the ‘credibility and competence of operators and leaders’ and ‘product safety and quality’ and reduce ‘goods disruption or delay due to inadequate supply mobility and poor financial performance’, ‘information system instability’, the ‘long product lead time’ and other key sustainable supply chain risks. The proposed framework can not only be effectively used by other electronics manufacturers to develop agile strategies to mitigate sustainable supply chain risks, but also provides a reference for risk management for manufacturers in other fields.

**Keywords:** multi-criteria decision-making; sustainable supply chain risk; supply chain agility; quality function deployment; electronic manufacturing



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## 1. Introduction

With increasingly fierce market competition and increasingly stringent environmental regulations, electronic enterprises need to effectively integrate environmental protection and social responsibility into their daily operations and supply chain operation management. Meanwhile, the importance of sustainable development of high-tech enterprises is particularly prominent [1]. Establishing an efficient and effective electronics manufacturing supply chain is important for both emerging and developed economies [2]. In the recent past, electronic manufacturing supply chains (EMSCs) have been challenged by many factors, including price fluctuations, climate change, information security and customer needs [3]. In particular, with the development of globalization, supply chain systems have become longer and more complex. Vulnerabilities and related supply chain risks increase with the complexity of the supply network [4], resulting in enterprises facing higher levels of risk [5].

As strategic and transparent systems for coordinating key business processes to achieve social, environmental and economic goals [6], sustainable supply chain systems help individual companies and their supply chains improve their long-term economic performance [7]. Therefore, scholars and business managers combine the concept of sustainable supply chain with supply chain risk management [8,9], arguing that sustainable practices can help reduce supply chain risks by continually focussing on mitigating sustainable supply chain risks (SSCRs) [9–12].

Recent studies have found that different resilience capabilities can improve supply chain resilience and reduce supply chain risk [13–15]. Resilience mainly includes agility, visibility, flexibility, collaboration, and information sharing. These studies mainly focus on the relationship between supply chain elasticity and supply chain risk, so some scholars regard a flexibility strategy as a valuable method when addressing risks [16]. Meanwhile, scholars regard improving supply chain agility (SCA) as a powerful and effective method that overcomes SSCRs [17–21]. However, as an important part of resilience, the empirical research on reducing the supply chain risk of agility is not extensive. The enhancement of agility is a risk management measure that can enable companies to respond quickly to market changes and disruptions in the supply chain [17]. SCA can help enterprises increase their performance and competitive advantage [22], improve supply chain elasticity and reduce supply chain risks. In the manufacturing sector [17,23,24], risk management and SCA have a direct impact, which plays an important role in determining an enterprise's performance. Therefore, the relationship between SSCRs and SCA is an important topic in both academia and industry [25–27].

While there are many studies on risks and agility, studies on supply chain risks and agility are few [25,28], and in-depth studies on the interdependence of SSCRs and SCA and on the internal dependence of SSCRs are almost absent [27,29]. In particular, in the field of electronics manufacturing supply chain, there are no studies on SSCRs and SCA, and studies using quality function deployment (QFD) are scarce. Accordingly, this study used QFD to improve SCA to mitigate SSCRs, and to analyse the mutual relationship and internal dependence between them. QFD was first used to support incremental, disruptive, and radical product innovations [30]. In recent years, it has been successfully applied in many fields to solve multicriteria decision-making (MCDM) problems, such as management system selection [31], supplier selection [32], determination priority of technical attributes [33], product quality design [34] and green supply chain management standard selection [35]. However, at present, research on EMSC which integrates QFD and MCDM methods to build a house of quality (HoQ) model to connect SSCR and SCA is not sufficient. Therefore, we herein discuss the following issues.

1. What are the key SSCRs and agility criterion for the EMSC?
2. How can the QFD-MCDM framework be used to construct a HoQ model to relate SSCRs and agility criteria and how can the model be applied to the multinational electronics manufacturing industry.
3. How does the relationship between SSCRs and agility criteria affect the search for feasible agile solutions to mitigate SSCRs in the EMSC?
4. For multinational electronics manufacturers, what are the most important SSCRs that should be mitigated, and which agility criteria should be applied to mitigate the most critical SSCRs in order to achieve a sustainable EMSC?

This study developed a QFD-MCDM framework to evaluate SSCRs and agility criteria in an EMSC to investigate effective agility decisions. The framework was used to identify and select a key rule of SSCRs and agility criteria, investigate the interdependence of SSCRs and the relationship between SSCRs and agility criteria, and, finally, determine the priority of SSCRs and agility criteria in the EMSC. Furthermore, a multinational electronic assembly manufacturing enterprise run by the United States in China was considered for a case study and the QFD-MCDM framework was used to provide useful agile decisions for the managers of the enterprise to mitigate SSCRs.

The contribution of this study involves four aspects: (1) So far, several qualitative and quantitative studies on SSCR have been carried out. However, empirical research on mitigating SSCRs from the perspective of improving SCA is not sufficient. Therefore, based on QFD, this study constructs a high-quality model of the relationship between SCA and SSCR. (2) Although some researchers have conceptually discussed the potential application of agility in risk control, the research linking SCA to SSCR in a decision framework based on survey data is not complete. We then combined QFD with MCDM to identify the most important criteria for SSCRs and agility. (3) This study uses a multinational enterprise as an example and employs the QFD-MCDM assessment framework to provide the case company with an agile solution that mitigates SSCRs. This framework can also be applied to other manufacturing enterprises. (4) This study enriches the theoretical research on SCA and SSCR, and it provides an empirical reference for the agility of supply chain risk management.

The rest of the paper is organized as follows: Section 2 identifies SSCRs and agility criteria from a literature review and outlines research gaps and highlights. Section 3 describes the QFD-MCDM integrated framework and its corresponding algorithm. Section 4 illustrates the empirical analysis and discussion with multinational electronic enterprises as an example. Finally, Section 5 summarizes the main contributions of this study and provides suggestions for future research.

## 2. Literature Review

For an organization and its supply chain to rapidly respond to unforeseen changes in the business in the face of competition and uncertainties pertaining to the environment, it is important to improve the agility of the supply chain. Furthermore, improved SCA can help decision makers identify SSCRs and formulate strategies for the sustainable growth of the organization [25]. A literature survey showed that few studies have investigated the relationship between SCA and SSCRs. Therefore, the focus of this study was to improve SCA to reduce SSCRs and thereby enhance the sustainability of EMSCs.

### 2.1. Sustainable Supply Chain Risk

A supply chain is a network comprising organizations, people, activities, technologies and information associated with the conversion of raw materials into finished products and the delivery of the products to consumers [36]. In supply chain management, network configuration is crucial for enterprises to pursue competitive advantages and meet market demands. The flexibility and agility of a supply chain can be improved by designing and optimizing its network [37]. Particularly for manufacturing systems, a common and accepted method of achieving agility is to manufacture products in geographically distinct locations that are connected by communication networks [38]. Dotoli et al. (2006) proposed different structures using directed graph knowledge and solution methods for objective optimization problems, and the resulting network set demonstrated improvements in terms of flexibility and agility [39].

Sustainability improves the efficient use of system resources, sustainable supply chain management is becoming a key strategy for enterprises [40]. By implementing sustainable operations, enterprises can pursue higher sustainable financial, social and environmental performance [41]. Ehtesham Rasi and Sohanian (2021) combined sustainable supplier selection with the optimization of sustainability performance indicators in the design of supply chain networks to design and optimize economic and environmental dimensions in sustainable supply chain networks [42]. Chowdhury and Quaddus (2020) proposed a theoretical proof and empirical verification of the direct and indirect conditional effect of supply chain sustainability on performance, and believed that the conditional indirect effect of supply chain sustainability on market performance through sustainable risk was significant [43]. In the supply chain, management of risks, such as credit risk [44–46], environmental risk [47–49], social risk [50] and energy risk [51,52], has always been of key importance. SSCR management can help to maintain or enhance the sustainability

of a supply chain, thereby contributing to the success and improvement of supply chain management. For example, Rostamzadeh et al. (2018) viewed supply chain sustainability as a risk management process and argued that a coordinated response to sustainability and supply chain risks would be appropriate [53]. Gouda and Saranga (2018) observed that sustainability helps reduce supply chain risks, especially in the environment of emerging markets [8]. Boiral et al. (2020) used grounded theory to conduct semi-structured interviews and qualitative analysis of practitioners participating in the activity, and investigated the rigor and reliability of sustainability rating agencies' assessment of corporate sustainability risk [54]. Hallikas et al. (2020) believe that sustainable procurement practices can improve the procurement performance of enterprises, and are of great significance for reputation improvement and business risk management [55]. Abdel-Basset and Mohamed (2020) stated that risk management should focus on identifying and analysing the impact of losses on enterprises, society and the environment and formulating strategies to maintain the sustainability of supply chains [11]. Victor et al. (2021) outline possible systemic risks in sectors with high impact potential for sustainable development such as agriculture, forestry and Marine resource extraction, and discuss the limitations of current governance mechanisms in addressing sustainability risks in these areas [56]. Moktadir et al. (2021) identified and analysed the key risk factors that should be considered to successfully implement sustainable supply chain management practices for achieving a sustainable supply chain [12]. Therefore, in order to realize sustainable supply chain, this study focuses on the risk of sustainable supply chain.

In order to achieve the sustainability supply chain and better understand the concept of SSCR management, this paper explains the risk classification of different scholars. Sakli et al. (2014) proposed five categories: chain internal risk (process risk and control risk), chain internal to external risk (demand risk and supply risk), and chain external risk (environmental risk) [57]. In an evaluation system for supplier selection, Rao et al. (2016) divided supply chain risks into seven categories: technical risk, information risk, management risk, economic risk, environmental risk, social risk and moral risk [58]. In an evaluation of suppliers, Mavi et al. (2016) considered the risk categories supply risk, demand risk, manufacturing risk, logistics risk, information risk and environmental risk [59]. From the perspective of SCA, Ganguly et al. (2017) divided risks into seven categories and defined organizational risk, intellectual property and regulatory risk, technical risk, supplier risk, information risk, quality risk, transportation risk and environmental risk [25]. Liu et al. (2018) divided supply chain risks into three categories: environmental risk, quality risk and operational risk [60]. Rostamzadeh et al. (2018) developed 7 major criteria and 44 sub-criteria for analysing supply chain risks using MCDM, including environmental risk, organizational risk, sustainable supply risk, sustainable production/manufacturing risk, sustainable distribution risk, sustainable recovery risk and information technology-related risk [53]. Liu et al. (2019) identified six risk categories, namely, market, sociopolitical and environmental, capacity, cooperation and coordination, alliance formation and risk commitment, and profit distribution [52]. Deng et al. (2019) classified the key risk factors of a perishable product supply chain: demand and raw material risk, employee risk, equipment risk, inventory risk, logistics risk, method risk, organizational risk, information risk and environmental risk [61]. In their risk analysis of a sustainable supply chain, Abdel-Basset and Mohamed (2020) divided risks into six categories: financial risk, supply risk factors, environmental risk, operational risk, control and planning risk, and information technology risk [11]. Jiang et al. (2020) divided risks into three categories in their evaluation of a sustainable supply chain of liquor: economic risk, environmental risk and social risk [62]. Badenhorst-Weiss and Naudé (2020) divided supply chain risks into five categories: financial risk, operational risk, external risk, market risk, and reputational risk [63]. Mzougui et al. (2020) divided supply chain risks into product characteristics, suppliers, transportation, financial risks, processing equipment and process realization [64]. Auer and Rauch (2021) classified supply chain risks into two categories: external risks and internal risks [65]. Zou et al. (2021) divided green supply chain risks into external risks,

internal risks and other risks, with ‘other risks’ including information factors, contract factors, default factors, environmental awareness and green design capabilities [66].

This study considered the risk classification of different scholars. Depending on the type of the risk of enterprise departments, SSCRs can be divided into five categories: external environment, enterprise product supply, suppliers’ material supply, human resource dimensions, and enterprise interior and equipment aspect. These SSCR categories cover the social, economic and environmental aspects of sustainability. Aspects of sustainability of the basis of the above discussion and a comprehensive review of the literature [9,10,53,61,67–99]. In this study, 80 SSCRs belonging to the aforementioned five categories were reviewed, as shown in Table A1 (Appendix A). These SSCRs are assessed in Section 4.

## 2.2. Supply Chain Agility

SCA refers to the ability of a supply chain to quickly adjust its strategy and operation [100]. This ability can help improve the operation of a company; for example, it can enable the company to formulate a coordinated and connected response to fluctuating market changes [18]. SCA also refers to the ability to overcome unexpected challenges in logistics and distribution systems when providing customer-driven products and services [101], and to survive and sustain when faced with unexpected threats in a dynamic and unstable business environment [102].

SCA enablers are used to define the overall agility capabilities, which are responsiveness, competency, flexibility, and quickness, required to be sustainable [103]. The assessment of SCA is very important because it is a strategic indicator of the sustainability status [104]. Many scholars have conducted research on the evaluation of SCA. For example, Dehgani and Navimipour (2019) used a structural equation modelling technique to verify that information technology has a significant impact on agility [105]. Mandal and Saravanan (2019) used a partial least squares method to analyse the impact of entrepreneurship orientation, environment orientation, supply chain orientation, technology orientation, market orientation and learning orientation on the development of agility and elasticity of a tourism supply chain [106]. Roscoe et al. (2020) applied the life cycle theory to a supply chain and established a hypothetical model of the independent and combined effects of internal and external process connection on SCA and the moderating effects of product and supply complexity to achieve an agile response to a continuous change [107].

In our attempt to comprehensively understand the concept of SCA through literature integration, we found that many scholars have performed different studies. Bargshady et al. (2016) noted that the main influencing factors of SCA are customer satisfaction, information technology, personnel, change and uncertainty, and advertising [108]. Mirghafoori et al. (2017) found that the impact of SCA on green performance is mainly through organizational strategy, customer satisfaction and financial performance [109]. In the evaluation of SCA, Wu et al. (2017) divided the evaluation criteria into five levels: collaboration, process integration, information integration, customer measures and strategic alliance [110]. Tooranloo et al. (2018) divided the indicators of green SCA into seven levels, namely customer relationship, supplier relationship, green performance, green marketing, green process integrity, intellectual capital and green IT [111]. Irfan et al. (2019) found that supply elasticity, process integration and product complexity have a positive effect on the improvement of SCA and hence influence the business performance of enterprises [112]. Rasyidi and Kusumasstuti (2020) evaluated the agility of a supply chain from four aspects: flexibility, responsiveness, effectiveness and maturity [113]. Shuko et al. (2020) observed that there is an interactive relationship between SCA and organizational flexibility, and that supply chain integration has a positive impact on enterprise SCA and organizational flexibility [114]. Rehman et al. (2020) and Al-Zabidi et al. (2021) argued that the drivers of SCA could be classified into six levels: organizational management, strategic management, information management, strategic commitment, customer sensitivity and interpersonal skills [115,116]. According to Jindal et al. (2021), the key determinants of agility mainly

could be classified into seven levels, namely infrastructure, supplier and customer information, analytical capabilities, human resources, management decision power, operational flexibility, and time change [117]. Aprilia et al. (2021) verified through examples that supplier innovation, information sharing and strategic resources have a significant impact on SCA [118].

In the light of the above discussion, this study divided SCA into six levels: cooperation and competition, information technology, market supply, customer relationship, manufacturing technology capability, organization and team management. Furthermore, according to the literature survey [108,119–137], 59 agility criteria were identified and classified into these 6 levels, as shown in Table A2 (Appendix A). These SCA criteria will be evaluated in Section 4.

### 2.3. Integrating Sustainable Risk and Agility for Supply Chain

In the study of SSCR, scholars analyze risks from multiple angles and dimensions. Some scholars believe that SCA and SSCR mutually influence each other. For example, Swafford et al. (2006) argued that organizations that consciously develop agility can manage interruption risks to ensure uninterrupted customer service [119]. Khan et al. (2008) and Braunscheidel et al. (2009) regarded the improvement of SCA as an outage risk management strategy, and they emphasized quick, proactive action in the face of potential outages [17]. From a theoretical perspective acquired from a literature survey, Aziz et al. (2015) proposed that agile practices have an impact on supply chain risks, and provided theoretical support for future research model building and empirical analysis [28]. Ganguly et al. (2017) assessed a set of key risks associated with SCA to help decision makers develop risk management strategies related to SCA to ensure growth and sustainability in the market [25]. Using structural equation models, Jajja et al. (2018) tested the hypothesis that supply chain risk improves agility performance [24]. Arifin (2018) claimed that supply chain risk management plays a significant regulating role for SCA, supply chain cost, supply chain responsiveness and global manufacturing activities [23]. Mandal and Dubey (2020) used a structural equation model to analyse the relationship between SSCR and agility [26]. Bhatti and Nawaz (2020) explored the impact of agility on sustainable tourism supply chain performance and hence on risk management in the Maldives tourism industry [27]. However, in the existing literature, empirical discussion on how SCA alleviates SSCRs is relatively lacking. Determining the impact of SCA on SSCR can help enterprises to formulate agile management strategies to prevent SSCR.

### 2.4. Research Gaps and Highlights

The EMSC is an important contributor to any national economy. With economic globalization and the increasingly fierce business environment, the sustainability of a supply chain is important for improving organizational performance and increasing competitive advantage [138]. Recent research has focused on the sustainability of the EMSC. For instance, Orji and Liu (2020) used fuzzy TOPSIS to discuss the impact of key drivers of innovation-led lean production on long-term sustainable performance in China's EMSC [139]. Rajesh (2018) considered the Indian EMSC as an example, studied the positioning of the supply network by combining sustainability with resilience [140]. In order to explain the objective contradiction between sustainability and resilience in practice, Rajesh (2021) proposed a grey objective decision making and tradeoff implementation model to analyze the strategic preference of electronic manufacturing enterprises for achieving sustainability and resilience [141]. However, past studies neither considered the impact of SSCRs and SCA on an EMSC nor not used SCA to eliminate or mitigate SSCRs. Therefore, this study investigated the impact of SSCRs and SCA on an EMSC and attempted to use SCA to mitigate SSCRs.

The main highlights of this study are as follows:

- A HoQ model was used to link SSCRs and agility criteria and apply them to the multinational electronics manufacturing industry.

- A HoQ model based on QFD was used to investigate the interdependence of SSCRs and agility criteria, and to determine important agility criteria to eliminate or mitigate major SSCRs.

### 3. Methodology

This section introduces a fuzzy Delphi method (FDM), the analytic hierarchy process (AHP), the decision-making trial and evaluation laboratory (DEMATEL) and grey relational analysis (GRA). Furthermore, a hybrid QFD-MCDM framework based on QFD and a combination of these MCDM methods is proposed to discuss how to mitigate SSCRs by improving SCA, and it is applied to the multinational electronics manufacturing industry.

#### 3.1. The Proposed QFD-MCDM Framework

QFD is a new-product development process that emphasizes cross-functional integration. It provides a means of translating customer requirements into final products (or services) through all stages of product planning, engineering, and manufacturing, and it is an effective way to ensure adequate quality at each stage of the product development and production process [142]. The customer requirement planning matrix, known as ‘HoQ’, is the central structure for QFD [143]. Customer requirements are usually obtained through market surveys or customer interviews, and they are converted into a set of measurable engineering characteristics to determine the relationship between customer requirements and engineering characteristics, obtain the correlation between engineering characteristics, and calculate the importance of the engineering characteristics [144].

The main limitation of traditional QFD is that the process is overly subjective and, in some cases, may lack flexibility [145]. To overcome this limitation, scholars have extensively studied the integration of MCDM into QFD [32,146–149]. MCDM is a method that can simultaneously consider multiple criteria and process evaluation information provided by decision makers; it can describe, evaluate and rank evaluation objects [150]. For example, Erol et al. (2022) proposed an integrated decision framework that includes a QFD approach based on MCDM and a set of hesitant fuzzy language terms to investigate the true potential of blockchain to address the circular economy [151]. He et al. (2021) developed a hybrid approach to Kano-DEMATEL-QFD that achieved optimal resilient solutions for maximum customer satisfaction and SSCR mitigation at a minimum investment cost [152]. Guo et al. (2021) proposed a new risk assessment method by combining QFD with the fuzzy G1 method, dual tuple language representation model and dynamic intuitionistic fuzzy MCDM to judge the impact of risk factors on network operation [153]. Hsu et al. (2021) discussed the risk mitigation methods that can maximize the resilience of sustainable supply chains for garment companies based on QFD combined with MCDM [15]. Hsu et al. (2021) integrated the MCDM approach with QFD sustainable supply chain disruption risk, resilience capability and resilience enhancement characteristics, and they ultimately improved supply chain resilience by mitigating sustainable risk [154]. Therefore, an integrated framework involving QFD, FDM, AHP, DEMATEL and GRA is proposed in this paper. The combination of QFD and MCDM can help improve SCA, alleviate SSCRs and provide decision support for multinational electronic manufacturing enterprises. The HoQ model and method flowchart of the QFD-MCDM framework used in this study are shown in Figures 1 and 2. The main analysis steps are as follows.

##### 3.1.1. Step 1: Screening out Key SSCRs and Agility Criteria Using FDM

Factors obtained from a literature survey included 80 SSCRs and 59 agility criteria. With the help of eight experts, the factors were evaluated and assigned a number from 0 to 10. The larger the number, the more important was the factor. In this study, an FDM was used to collate expert opinions, and the threshold value  $G^i$  was used to calculate the SSCRs and agility criteria. The key SSCRs and agility criteria were screened out. They correspond to ① and ② in Figure 1, respectively.

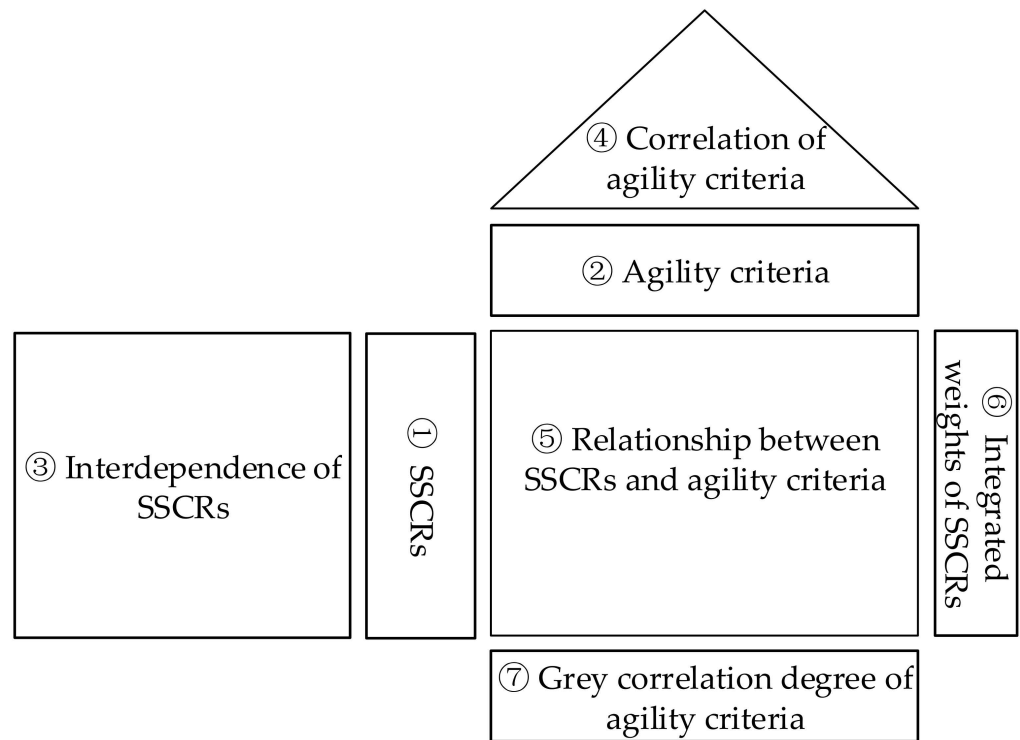


Figure 1. Structure of the HoQ.

3.1.2. Step 2: Calculating the Weights of Key SSCRs Using AHP

In terms of the AHP evaluation scale, SSCRs within the same level were compared pairwise by means of an expert questionnaire, a comparison matrix was constructed, and the weight of each SSCR was calculated, so as to prepare for the next calculation of the integrated weights of the SSCRs.

3.1.3. Step 3: Obtaining the Correlation Matrix between Key SSCRs Using DEMATEL

The evaluation results of each expert were sorted into an  $n \times n$  direct relation matrix to assess the inherent dependencies between SSCRs. The original correlation matrix and comprehensive impact matrix T for the SSCRs were obtained by using DEMATEL (i.e., the direct relation matrix ③ of the SSCRs, which is located in the leftmost part of the HoQ model in Figure 1).

3.1.4. Step 4: Obtaining the Correlation of Agility Criteria and the Matrix of the Relationship between SSCRs and Agility Criteria

The questionnaire results for the agility criteria were defuzzified to obtain their direct relation matrix (④), which is located on the roof of the HoQ in Figure 1. “Defuzzification” is an important step in fuzzy inference machines, and it refers to transforming the fuzzy quantity obtained by expert decision into an accurate quantity, that is, to deduce the mapping from a fuzzy set to a general set. In order to determine the correlation between SSCRs and agility criteria, we used a numerical representation: 1, 3 and 9 represented low, moderate and high correlation, respectively. The relational matrix (⑤) of SSCRs and agility criteria obtained by defuzzifying the questionnaire data is located in the middle of the HoQ in Figure 1.



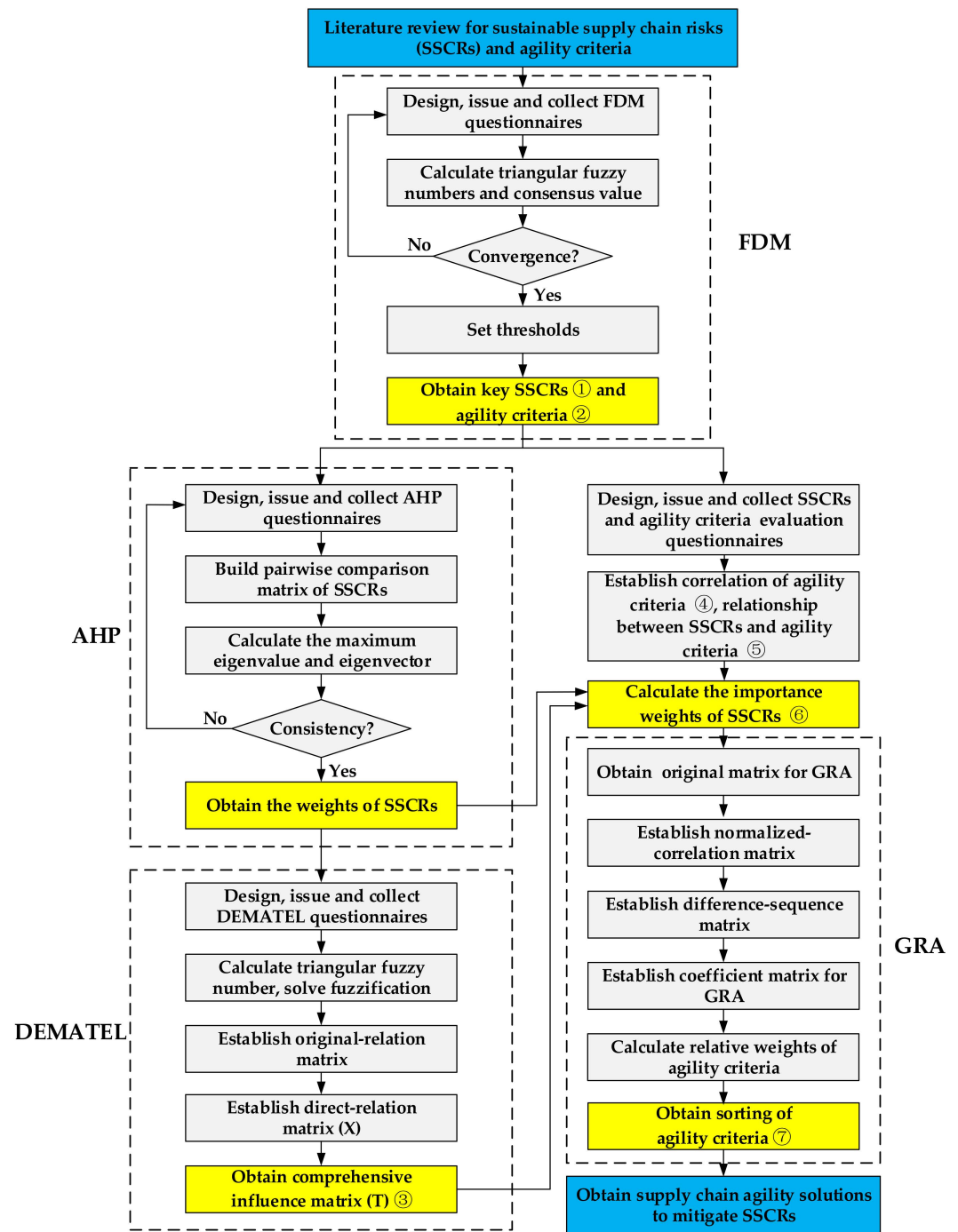


Figure 2. Proposed QFD-MCDM framework.

### 3.1.5. Step 5: Sorting the Agility Criteria Using GRA

The direct relation matrix of agility criteria obtained in step 4 was multiplied by the mutual relation matrix of SSCRs and agility criteria in step 4 to obtain the original matrix of GRA. Using GRA, the integrated weight (⑥) of SSCRs and the grey correlation (⑦) of agility criteria were obtained; they are located to the right and below the HoQ in Figure 1, respectively. Finally, the agility criteria were ranked according to the grey correlation degree.

### 3.2. Fuzzy Delphi Method

An FDM was proposed by Ishikawa et al. (1993) on the basis of the traditional Delphi technique and fuzzy reasoning [155]. Unlike the traditional Delphi method, it had shortcomings, such as low consistency of expert opinions and high cost of execution and modification of individual expert opinions in order to achieve an overall consensus. Chang et al. (2000) pointed out that FDM used for group decision-making could solve the problem of ambiguity of expert consensus [156]. FDM can reduce the number of investigations, time and cost and consider expert opinions [157]. Rathore et al. (2021) identified 15 associated safety risk factors using FDM to achieve a safe working environment in the healthcare system [158]. In sustainable supply chain management, Chen et al. (2021) identified nine key risk factors using FDM as determinants of the case firm’s improvement measures [159]. This study adopted an FDM to screen key SSCRs and agility criteria. The specific processes are as follows:

Step 1: Identify all the evaluation factors, design a fuzzy Delphi expert questionnaire, and ask each expert to evaluate the importance of the factor, that is, to provide an interval value. The ‘minimum value’ of the interval value represents the ‘most conservative value’ of the expert’s quantification score for this factor. Conversely, the ‘maximum value’ represents the ‘most optimistic value’ of the expert’s quantified score for the factor.

Step 2: The questionnaires of experts were collected and integrated, the ‘most conservative value’ and ‘most optimistic value’ provided by all experts were considered and the extreme value falling beyond twice the standard deviation was eliminated. Fuzzy theory was then used to calculate the minimum value  $C_L^i$ , geometric mean value  $C_M^i$  and maximum value  $C_U^i$  of the remaining ‘most conservative value’, and the minimum value  $O_L^i$ , geometric mean value  $O_M^i$  and maximum value  $O_U^i$  of the ‘most optimistic value’. The triangular fuzzy number is shown in Figure 3.

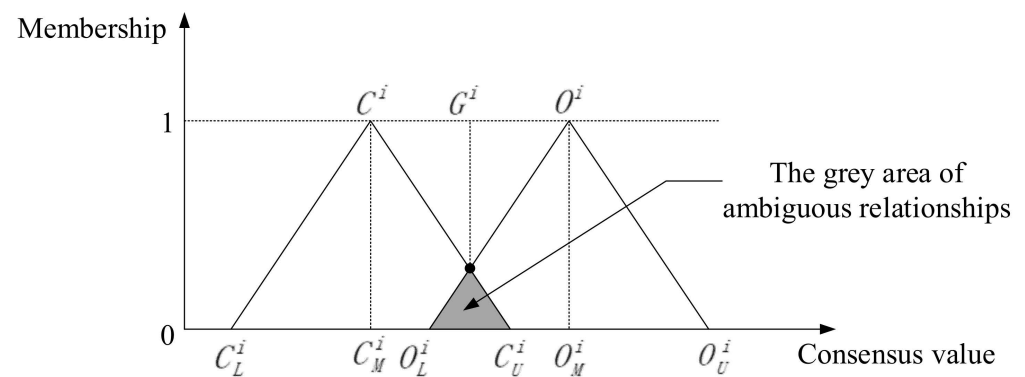


Figure 3. Schematic of FDM triangular fuzzy number.

Step 3: Calculate the degree of consensus  $G^i$  of expert opinions and test whether the opinions of experts reached a consensus. The higher the value, the higher the consensus of experts on this factor.  $G^i$  can be computed in the following three ways.

- (1) If the two triangular fuzzy numbers do not overlap, that is,  $(C_U^i \leq O_L^i)$ , it indicates that there is no consensus on the value of the expert opinion range. Then,  $G^i$  of this evaluation factor is the arithmetic mean of  $C_M^i$  and  $O_M^i$ , and it is expressed as  $G^i = (C_M^i + O_M^i) / 2$ .
- (2) If the two triangular fuzzy numbers overlap, that is,  $(C_U^i > O_L^i)$ , and  $M^i < Z^i$ ,  $M^i$  is the interval range of optimistic and conservative cognition, and it is given by  $M^i = O_M^i - C_M^i$ .  $Z^i$  is the grey area of fuzzy relationship, and it can be expressed as  $Z^i = C_U^i - O_L^i$ . Although there is no consensus between the opinions of the experts, in the case of the experts who give the extreme opinions, their opinions do not differ

significantly from the opinions of the other experts to cause differences of opinions.  $G^i$  of this factor is calculated by the formula.

$$G^i = \frac{[(C_U^i \times O_M^i) - (O_L^i \times C_M^i)]}{[(C_U^i - C_M^i) + (O_M^i - O_L^i)]} \tag{1}$$

- (3) If the two triangular fuzzy numbers overlap, that is,  $(C_U^i > O_L^i)$ , and  $M^i > Z^i$ , it indicates that the expert who gave the opinion corresponding to the extreme value differs too much from the other experts, resulting in divergence of opinion.

Step 4: The evaluation factors that do not converge are provided to experts for reference, and steps 1–4 are repeated until all the evaluation factors converge and  $G$  is solved.

Step 5: Set reasonable thresholds  $G^i$  and screen out key factors and criteria.

### 3.3. Analytic Hierarchy Process

The AHP was proposed by Saaty (1977) to deal with the MCDM problem, and it is also one of the most widely used methods [160,161]. It has the capability to solve multi-person, multi-attribute and multi-cycle problems with a layered complex structure [162]. The AHP can also deal with both tangible and intangible factors and is believed to improve the accuracy of the evaluation, selection and resource allocation stages of decision-making, helping decision makers to independently judge the contribution of each criterion to the goal [163]. For instance, Bathrinath et al. (2021) determined the most influential risks and preventive measures using a hybrid multi-criteria decision method such as AHP and adding a similar ranking technique to the ideal scheme [164]. Tavana et al. (2021) proposed a comprehensive method for supply chain risk-benefit assessment and supplier selection by combining fuzzy AHP with fuzzy multiplication multi-objective optimization based on ratio analysis [165]. Therefore, this study used the AHP to evaluate the importance of SSCRs.

Table 1 presents the assessment scale of the AHP; as shown, it divides the importance into nine levels.

Table 1. AHP assessment scale.

| Assessment Scale | Definition                    | Instruction  |
|------------------|-------------------------------|--|
| 1                | Important                     | Both are of equal importance.                                    |
| 3                | A little important            | As a rule of thumb, one indicator is slightly more important.    |
| 5                | Quite important               | As a rule of thumb, one indicator matters.                       |
| 7                | Very important                | As it turns out, a certain indicator is very important.          |
| 9                | Absolutely important          | There is ample evidence that one metric is absolutely important. |
| 2, 4, 6, 8       | The median of adjacent scales | A value  |

The various steps involved in the AHP are as follows:

Step 1: Make a pairwise comparison of factors within the same level and establish a pairwise comparison matrix according to the results of the questionnaire survey, as shown below:

$$A = [a_{ij}] = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{bmatrix}, \tag{2}$$

Step 2: Calculate the weight of the elements at each level by comparing the matrices in pairs, and then calculate the eigenvector  $W$  and the maximum eigenvalue  $\lambda_{max}$  to check whether the matrices are consistent. The formula is as follows:

$$A = [a_{ij}] = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{bmatrix} * \begin{bmatrix} W_1 \\ W_2 \\ \vdots \\ W_n \end{bmatrix} = \begin{bmatrix} W'_1 \\ W'_2 \\ \vdots \\ W'_n \end{bmatrix}, \tag{3}$$

$$\lambda_{max} = (1/m) * (W'_1/W_1 + W'_2/W_2 + \dots + W'_n/W_n), \tag{4}$$

Step 3: The pairwise comparison matrix is constructed by using *C.I.* (Consistency Index) and *C.R.* (Consistency Ratio) to calculate *C.R.* When  $C.R. \leq 0.1$ , it means that the matrix passes the consistency test; otherwise, the questionnaire should be filled out again to ensure the accuracy of the data.

$$C.R. = C.I./R.I., \tag{5}$$

$$C.I. = (\lambda_{max} - n)/(n - 1), \tag{6}$$

Here, *R.I.* is the stochastic index. Table 2 lists the stochastic index for  $n$  factors.

**Table 2.** Stochastic index.

| (n)         | 1 | 2 | 3    | 4   | 5    | 6    | 7    | 8    | 9    | 10   | 11   | 12   |
|-------------|---|---|------|-----|------|------|------|------|------|------|------|------|
| <i>R.I.</i> | 0 | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 | 1.51 | 1.48 |

### 3.4. DEMATEL

The DEMATEL method is a comprehensive method to establish and analyse a structural model of the causal relationship between complex factors [166,167]. It can be used to solve the problem of dependency and complexity between standards [168]. DEMATEL is based on a directed graph, which can divide the factors involved into cause groups and effect groups [166]. For example, He et al. (2021) used DEMATEL to determine the interrelationships of risk factors in their search for optimal resilient solutions that mitigate SSCR [152]. Li and Xu (2021) applied fuzzy DEMATEL analysis to determine and evaluate the relationship between accident risk factors and to calculate their weights; this strategy can help prevent accidents and improve system reliability [169]. Therefore, this study used DEMATEL to investigate the inherent dependence of SSCRs. The steps are detailed below.

Step 1: Five rating scales are used to evaluate the relationship between the factors. The five rating scales can be interpreted as follows: 0, no impact; 1, very low impact; 2, low impact; 3, high impact; and 4, very high impact. The relationship between the factors is converted into corresponding values, and the weight value of the influence degree of each factor is obtained after solving for the fuzzy average value.

The way to solve fuzziness is as follows: the maximum and minimum values of the evaluation values obtained from an expert questionnaire are considered as the two end points of the triangular fuzzy number  $T_i = (L_i, M_i, U_i)$ . The formulas are as follows:

$$L_i = \min(X_i) \tag{7}$$

$$M_i = \sqrt[n]{\prod_{i=1}^n X_i}, \tag{8}$$

$$U_i = \max(X_i), \tag{9}$$

Here,  $i$  ( $= 1, \dots, n$ ) is the number of experts,  $X_i$  is the evaluation value of a paired comparison of experts,  $L_i$  is the minimum evaluation value,  $U_i$  is the maximum evaluation value and  $M_i$  is the geometric mean of all the evaluation values. Finally, the arithmetic mean of the three values is obtained using the following formula to achieve the final solution fuzziness.

$$(L_i + M_i + U_i)/3, \tag{10}$$

Step 2: The influence degree obtained from the questionnaire is used to construct the original relational matrix  $Z$  of  $n$  factors, and the diagonal of the  $n \times n$  matrix is 0.

Step 3: The original relational matrix  $Z$  is normalized, and each row/column is summed, and the maximum value of the sums of the rows/columns is selected for the normalization of the matrix. The normalized direct relational matrix  $X$  can be obtained by using Formula (6).

$$\lambda = \frac{1}{\max_{1 \leq i \leq n} \left( \sum_{j=1}^n Z_{ij} \right)}, \tag{11}$$

Step 4: On the basis of the substitution of the normalized direct relation matrix  $X$  into Formula (7), it can be concluded that the total relation affects the matrix  $T$ , where  $I$  is the identity matrix.

$$T = X \times (I - X)^{-1}, \tag{12}$$

Step 5: Each row and each column in the total influence relation matrix  $T$  are summed up to obtain the sum of all rows ( $D$ ) and the sum of all columns ( $R$ ). A causality diagram is drawn with  $D_i + R_j$  as the abscissa coordinate and  $D_i - R_j$  as the ordinate.

### 3.5. Grey Relational Analysis

GRA was proposed by Julong (1982) on the basis of the grey relational space theory. It is used to solve uncertainty problems in the case of discrete data and incomplete information [170,171]. Because it is suitable for solving multi-factor and multi-variable problems with complex interrelations and since it uses relatively few data or factors with large variables to provide satisfactory results [172,173], it is a useful method for dealing with little, incomplete and uncertain information [172]. For instance, Zou et al. (2021) used GRA to clarify the degree of connection between supply chain risk factors and the selection of key risk factors to determine the risk factors involved in green supply chain management [64]. Huang et al. (2021) used the GRA model to evaluate the financial supply chain risks of 15 small and medium-sized enterprises in China’s home appliance industry [174]. Therefore, GRA was used in this study to evaluate the relationship between SSCRs and agility criteria, the internal dependence of agility criteria, and the grey correlation degree of agility criteria. The GRA steps are described below.

Step 1: Construct the original matrix. The normalized direct relation matrix  $X$  is set as the GRA original matrix, and grey correlation analysis is conducted on it.

Step 2: Perform normalization processing of the large feature to transform the original matrices of different definitions or units into comparable sequences.

$$X_i(k) = \frac{X_i^0(k) - \min_i X_i^0(k)}{\max_i X_i^0(k) - \min_i X_i^0(k)}, \tag{13}$$

Step 3: Calculate the gap between each normalized value and the reference data value by using the grey correlation distance formula

$$\Delta_{0i}(k) = |X_0(k) - X_i(k)|, \tag{14}$$

Step 4: Calculate the grey correlation coefficient:

$$\gamma(X_0(k), X_i(k)) = \frac{\min_{i \in N} \min_{k \in K} |X_0(k) - X_i(k)| + \zeta \max_{i \in N} \max_{k \in K} |X_0(k) - X_i(k)|}{|X_0(k) - X_i(k)| + \zeta \max_{i \in N} \max_{k \in K} |X_0(k) - X_i(k)|}, \tag{15}$$

Here,  $\zeta$  is the distinguished coefficient, with  $\zeta \in [0.1]$ , it means to control the size of the grey correlation coefficient for convenience of judgment. It is generally recommended to set it at 0.5, but decision makers can choose different  $\zeta$  values for calculations, depending on their personal preferences.

Step 5: Obtain the grey correlation degree of the criteria:

$$\Gamma_{oi} = \sum_{k=1}^n [W_k * \gamma(X_0(k), X_i(k))], \quad (16)$$

Step 6: Evaluate and sort according to the grey correlation degree of each criterion.

#### 4. Results and Discussions

Currently, EMSCs are facing unprecedented risks because of internationalization, the development of globalization, the increasing consumer demand, and the unpredictability of various natural and man-made disasters. In the fierce market, to maintain competitiveness, increase profits and reduce losses are the main objectives of current electronic manufacturing enterprises to manage risks. In this context, this study examined whether reducing SSCRs by improving SCA improved the sustainability of an EMSC.

In this study, a multinational electronic assembly manufacturing enterprise run by the United States in China was considered as the research object. Case Company's main business is the design and manufacture of electrical, electronic and fibre-optic connectors and cables, and its products are widely used in 3C, aerospace, military, automotive and railway applications. At present, the company faces SSCRs that are troubling business managers. In order to mitigate SSCRs and improve the company's SCA, this study collected different opinions from enterprises through expert interviews and questionnaires and performed a comprehensive analysis and judgment. The questionnaire information was mainly obtained from eight experts from different departments, with a recovery rate of 100%. The analysis results will be presented in the form of a HoQ.

##### 4.1. Results of Implementing the QFD-MCDM Approach

This study's calculation process is a relatively simple mathematical operation, which can be realized in Excel. Therefore, all the analysis in this study was completed in Excel. The following are the main steps of the QFD-MCDM approach:

###### 4.1.1. Step 1: Screening out Key SSCRs and Agility Criteria Using FDM

On the basis of 80 SSCRs and 59 agility criteria, a questionnaire pertaining to the FDM was designed and distributed in this study.

In this process, Formula (1) was used to calculate the value of G and set an appropriate threshold value of S to achieve the purpose of screening. After the experts' joint discussion, the threshold value was determined to be risk 5.1 and agility 5.0, and the screening conditions were as follows: If  $G \geq 5.1$ , the SSCRs are accepted. Otherwise, delete. If  $G \geq 5.0$ , the agility criteria are accepted. Otherwise, delete.

After screening by the FDM, the original 80 SSCRs were reduced to 19, and the original 59 agility criteria were reduced to 20. After screening, the important SSCRs and agility criteria were integrated, as shown in Tables 3 and 4.

**Table 3.** Key SSCRs after screening.

| No. | Sustainable Supply Chain Risks (SSCRs)   | $G_i$ |
|-----|--|-------|
| R1  | Product safety and quality   | 7.884 |
| R2  | Staff information was leaked   | 7.250 |
| R3  | Illegal operation by an employee   | 6.643 |
| R4  | Inadequate information security and information leakage  | 6.536 |
| R5  | Information system instability   | 6.205 |
| R6  | Bullwhip effect  | 5.857 |
| R7  | Man-made accidents   | 5.804 |
| R8  | IT and information sharing   | 5.750 |
| R9  | Disruption or delay in the delivery of goods because of inadequate liquidity and poor financial conditions | 5.661 |
| R10 | Credibility and competence of operators and leaders  | 5.536 |
| R11 | The company's financial management and control process, poor management policies                           | 5.536 |
| R12 | The company's market share has decreased   | 5.536 |
| R13 | Brand reputation is damaged, corporate culture is consistent   | 5.438 |
| R14 | Reductions in poor-quality materials have resulted in termination of supply                                | 5.393 |
| R15 | Failure to deliver on time, affecting customer expectations  | 5.384 |
| R16 | Working conditions at production centres are poor  | 5.339 |
| R17 | Supply chain accidents, delivery delays and a decline in the company's reputation                          | 5.268 |
| R18 | Data missing, unable to obtain part of the information   | 5.196 |
| R19 | Long product lead time   | 5.134 |

**Table 4.** Key agility criteria after screening.

| No. | Agility Criteria  | $G_i$ |
|-----|---|-------|
| A1  | Production and sales capability   | 8.125 |
| A2  | Improve customer satisfaction   | 6.938 |
| A3  | Shorten development cycle/enhance product innovation by improving R&D capability/new product launch frequency | 6.875 |
| A4  | Establish partnerships with other enterprises/implement win-win cooperation strategies with suppliers         | 6.875 |
| A5  | Reduce manufacturing lead time/lead time for quick response/synchronous engineering                           | 6.625 |
| A6  | Establish long-term cooperation and trust relationship with partners  | 6.563 |
| A7  | Quick customer response   | 6.438 |
| A8  | Accuracy of data  | 6.313 |
| A9  | Improve customer service  | 6.250 |
| A10 | Supplier on-time delivery rates   | 6.125 |
| A11 | Quick decision/strategic flexibility  | 5.938 |
| A12 | Improve delivery reliability  | 5.938 |
| A13 | Quality improvement   | 5.750 |
| A14 | Reduce delivery time, that is, achieve delivery time control  | 5.750 |
| A15 | Electronic shipment of finished products to control shipment operations                                       | 5.625 |
| A16 | Cost minimization   | 5.500 |
| A17 | Actively build an information sharing platform with partners  | 5.313 |
| A18 | Enhance brand value   | 5.188 |
| A19 | Adopt e-business  | 5.125 |
| A20 | Manage the core competitiveness of the enterprise   | 5.063 |

#### 4.1.2. Step 2: Calculating the Weights of Key SSCRs Using AHP

The analysis hierarchy is shown in Table 5 according to the 19 key SSCRs, which were screened out based on FDM during step 1 and involved 4 risk levels. The risk levels were compared in pairs, and the SSCRs of each level were compared in pairs. Five AHP

questionnaire forms were designed and sent to eight experts. Each expert made only 121 comparisons, and the calculation process used by each expert was the same. Only the input variables were changed, and the analysis process was repeated 8 times. The analytic process and AHP results are shown below.

1. The questionnaire data provided by experts were sorted and substituted into Equations (5) and (6) to check whether the answers on each aspect of the questionnaire met the consistency requirement, namely  $C.R. \leq 0.1$ . If the requirement was not met, the answers were discussed with the experts again, and the answers were entered in the questionnaire again. The calculation results of the dimension weight of the AHP expert questionnaire are presented in Table 8.
2. The weight of key SSCRs could be integrated by multiplying the weight of each factor by the weight of the corresponding dimension. This is shown in Tables 6 and 9–11.
3. According to the calculation steps of the expert questionnaire (1), the data of eight experts can be calculated and sorted to obtain the integrated weight of each expert’s score. The integrated weight value of the eight expert questionnaires can be calculated and averaged to obtain the final AHP weight, as shown in Table 7.

**Table 5.** Key SSCRs analysis hierarchy.

| Risk Levels                             | Sustainable Supply Chain Risks (SSCRs)  |
|---|---|
| RA1: Human resources                    | R2: Staff information was leaked<br>R3: Illegal operation by an employee<br>R7: Man-made accidents<br>R10: Credibility and competence of operators and leaders  |
| RA2: Supplier material supply           | R9: Disruption or delay in the delivery of goods because of inadequate liquidity and poor financial conditions<br>R12: The company’s market share has decreased<br>R14: Reductions in poor-quality materials have resulted in termination of supply   |
| RA3: Enterprise product supply          | R1: Product safety and quality<br>R15: Failure to deliver on time, affecting customer expectations<br>R16: Working conditions at production centres are poor<br>R19: Long product lead time   |
| RA4: Enterprise interiors and equipment | R4: Inadequate information security and information leakage<br>R5: Information system instability<br>R6: Bullwhip effect<br>R8: IT and information sharing<br>R11: The company’s financial management and control process, poor management policies<br>R13: Brand reputation is damaged, corporate culture is consistent<br>R17: Supply chain accidents, delivery delays and a decline in the company’s reputation<br>R18: Data missing, unable to render part of the information |

**Table 6.** The consistency and weight value of human resource (RA1) factors.

| Expert 1 | R2  | R3 | R7 | R10 | Criteria Weight | Integration Weight |
|----------|-----|----|----|-----|-----------------|--------------------|
| R2       | 1   | 2  | 1  | 1   | 0.2858          | 0.0579             |
| R3       | 1/2 | 1  | 1  | 1   | 0.2166          | 0.0439             |
| R7       | 1   | 1  | 1  | 1   | 0.2488          | 0.0504             |
| R10      | 1   | 1  | 1  | 1   | 0.2488          | 0.0504             |

$\lambda_{max} = 4.0604$ ;  $C.I = 0.0201$ ;  $C.R = 0.0224$



**Table 7.** The final weight of each SSCR.

| No. | Expert 1 | Expert 2 | Expert 3 | Expert 4 | Expert 5 | Expert 6 | Expert 7 | Expert 8 | AHP Weight |
|-----|----------|----------|----------|----------|----------|----------|----------|----------|------------|
| R12 | 0.1681   | 0.1381   | 0.1329   | 0.0968   | 0.1403   | 0.1090   | 0.0920   | 0.1390   | 0.1270     |
| R14 | 0.1059   | 0.1381   | 0.1522   | 0.1537   | 0.1113   | 0.0865   | 0.0730   | 0.1103   | 0.1164     |
| R1  | 0.0580   | 0.0759   | 0.1027   | 0.0961   | 0.1126   | 0.1289   | 0.1317   | 0.0935   | 0.0999     |
| R9  | 0.0667   | 0.0691   | 0.0580   | 0.0405   | 0.0884   | 0.1374   | 0.1160   | 0.0876   | 0.0829     |
| R15 | 0.0488   | 0.0577   | 0.0656   | 0.0679   | 0.0720   | 0.0655   | 0.0841   | 0.0661   | 0.0660     |
| R2  | 0.0579   | 0.0709   | 0.0584   | 0.0594   | 0.0445   | 0.0370   | 0.0315   | 0.0415   | 0.0501     |
| R10 | 0.0504   | 0.0501   | 0.0491   | 0.0465   | 0.0492   | 0.0370   | 0.0375   | 0.0415   | 0.0452     |
| R19 | 0.0345   | 0.0408   | 0.0390   | 0.0404   | 0.0428   | 0.0352   | 0.0500   | 0.0393   | 0.0402     |
| R13 | 0.0419   | 0.0356   | 0.0356   | 0.0447   | 0.0339   | 0.0390   | 0.0393   | 0.0395   | 0.0387     |
| R5  | 0.0384   | 0.0343   | 0.0343   | 0.0410   | 0.0339   | 0.0390   | 0.0393   | 0.0395   | 0.0375     |
| R11 | 0.0384   | 0.0326   | 0.0326   | 0.0389   | 0.0322   | 0.0404   | 0.0407   | 0.0375   | 0.0367     |
| R16 | 0.0290   | 0.0310   | 0.0353   | 0.0404   | 0.0387   | 0.0310   | 0.0452   | 0.0393   | 0.0362     |
| R18 | 0.0384   | 0.0326   | 0.0326   | 0.0389   | 0.0322   | 0.0371   | 0.0373   | 0.0375   | 0.0358     |
| R17 | 0.0384   | 0.0326   | 0.0326   | 0.0357   | 0.0296   | 0.0340   | 0.0342   | 0.0344   | 0.0339     |
| R3  | 0.0439   | 0.0421   | 0.0348   | 0.0353   | 0.0315   | 0.0262   | 0.0265   | 0.0293   | 0.0337     |
| R7  | 0.0504   | 0.0421   | 0.0292   | 0.0319   | 0.0284   | 0.0262   | 0.0315   | 0.0293   | 0.0336     |
| R4  | 0.0340   | 0.0289   | 0.0289   | 0.0344   | 0.0311   | 0.0358   | 0.0342   | 0.0395   | 0.0333     |
| R8  | 0.0352   | 0.0299   | 0.0299   | 0.0357   | 0.0296   | 0.0340   | 0.0342   | 0.0344   | 0.0329     |

**Table 8.** Consistency and weight values of the surface.

| Expert 1 | RA1 | RA2 | RA3 | RA4 | Weight |
|----------|-----|-----|-----|-----|--------|
| RA1      | 1   | 1/2 | 1   | 1   | 0.2026 |
| RA2      | 2   | 1   | 2   | 1   | 0.3407 |
| RA3      | 1   | 1/2 | 1   | 1/2 | 0.1703 |
| RA4      | 1   | 1   | 2   | 1   | 0.2865 |

$\lambda_{max} = 4.0604$ ; C.I = 0.0201; C.R = 0.0224

**Table 9.** The consistency and weight value of supplier material supply (RA2) factors.

| Expert 1 | R9 | R12 | R14 | Criteria Weight | Integration Weight |
|----------|----|-----|-----|-----------------|--------------------|
| R9       | 1  | 1/2 | 1/2 | 0.1958          | 0.0667             |
| R12      | 2  | 1   | 2   | 0.4934          | 0.1681             |
| R14      | 2  | 1/2 | 1   | 0.3108          | 0.1059             |

$\lambda_{max} = 3.0536$ ; C.I = 0.0268; C.R = 0.0462

**Table 10.** The consistency and weight value of enterprise product supply (RA3) factors.

| Expert 1 | R1  | R15 | R16 | R19 | Criteria Weight | Integration Weight |
|----------|-----|-----|-----|-----|-----------------|--------------------|
| R1       | 1   | 2   | 2   | 1   | 0.3407          | 0.0580             |
| R15      | 1/2 | 1   | 2   | 2   | 0.2865          | 0.0488             |
| R16      | 1/2 | 1/2 | 1   | 1   | 0.1703          | 0.0290             |
| R19      | 1   | 1/2 | 1   | 1   | 0.2025          | 0.0345             |

$\lambda_{max} = 4.1836$ ; C.I = 0.0612; C.R = 0.0680

**Table 11.** The consistency and weight value of enterprise interiors and equipment (RA4) factors.

| Expert 1 | R4  | R5  | R6 | R9 | R11 | R13 | R17 | R18 | Criteria Weight | Integration Weight |
|----------|-----|-----|----|----|-----|-----|-----|-----|-----------------|--------------------|
| R4       | 1   | 1   | 3  | 1  | 1/2 | 1/2 | 1   | 1   | 0.1186          | 0.0340             |
| R5       | 1   | 1   | 2  | 1  | 1   | 1   | 1   | 1   | 0.1341          | 0.0384             |
| R6       | 1/2 | 1/2 | 1  | 1  | 1   | 1/2 | 1/2 | 1/2 | 0.0758          | 0.0217             |
| R9       | 1   | 1   | 1  | 1  | 1   | 1   | 1   | 1   | 0.1230          | 0.0352             |
| R11      | 2   | 1   | 1  | 1  | 1   | 1   | 1   | 1   | 0.1341          | 0.0384             |
| R13      | 2   | 1   | 2  | 1  | 1   | 1   | 1   | 1   | 0.1462          | 0.0419             |
| R17      | 1   | 1   | 2  | 1  | 1   | 1   | 1   | 1   | 0.1341          | 0.0384             |
| R18      | 1   | 1   | 2  | 1  | 1   | 1   | 1   | 1   | 0.1341          | 0.0384             |

$\lambda_{max} = 8.2209$ ; C.I = 0.0316; C.R = 0.0224

4.1.3. Step 3: Obtaining the Correlation Matrix between Key SSCRs Using DEMATEL

In this process, DEMATEL was used to consider the interaction between SSCRs and serve as the impact matrix on the left side of the HoQ.

1. The defuzzification calculation was performed by substituting the questionnaire data of eight experts into Equations (7)–(10) for data defuzzification and obtaining the influence degree of R1 on the remaining 18 factors as an example. Similarly, the mutual influence degree values among the 19 factors were calculated to obtain the original relational matrix (shown in Table 12). The sum of each row/column of the original relational matrix was obtained, and the maximum value of the sums of the rows/columns was selected for the normalization of the matrix. The maximum value obtained was 41.875.
2. Substituting the original relational matrix into Equation (11) yielded  $\lambda = 0.0239$ . The value of  $\lambda$  was multiplied by the original relational matrix; in other words, the normalized direct relational matrix could be obtained by normalizing the original relational matrix. Equation (12) was used to obtain the comprehensive influence matrix T, which is shown in Table 14.
3. The data in Table 13 were obtained by summing each row/column of the comprehensive influence matrix T and adding and subtracting the influence degree  $D_i$  of the factors and the influence degree  $R_j$ .

**Table 12.** Raw relational matrix of SSCRs.

| No. | R1     | R2    | R3    | R4     | R5    | R6    | R7     | R8     | R9     | R10    | R11    | R12    | R13    | R14    | R15    | R16   | R17    | R18    | R19    | Sum    |
|-----|--------|-------|-------|--------|-------|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-------|--------|--------|--------|--------|
| R1  | 0.000  | 0.000 | 0.458 | 0.000  | 0.375 | 0.000 | 1.458  | 0.375  | 0.375  | 3.375  | 0.375  | 0.833  | 3.292  | 4.500  | 2.375  | 0.375 | 3.458  | 0.375  | 2.542  | 24.542 |
| R2  | 0.917  | 0.000 | 0.375 | 0.875  | 3.917 | 0.000 | 0.375  | 0.833  | 1.333  | 2.958  | 1.583  | 1.250  | 1.750  | 0.917  | 0.792  | 0.375 | 1.750  | 3.500  | 0.375  | 23.875 |
| R3  | 2.917  | 0.375 | 0.000 | 0.458  | 0.500 | 1.333 | 4.167  | 0.375  | 0.000  | 1.042  | 0.375  | 0.375  | 2.208  | 1.208  | 0.542  | 0.500 | 0.417  | 1.375  | 0.792  | 18.958 |
| R4  | 2.958  | 0.833 | 0.000 | 0.000  | 0.458 | 0.792 | 0.375  | 0.875  | 0.000  | 1.042  | 0.375  | 0.875  | 3.000  | 0.417  | 0.375  | 0.000 | 0.417  | 3.125  | 0.833  | 16.750 |
| R5  | 0.458  | 0.375 | 0.000 | 2.167  | 0.000 | 0.417 | 0.000  | 2.958  | 2.417  | 0.458  | 2.958  | 4.083  | 4.125  | 0.917  | 0.000  | 0.375 | 0.417  | 4.042  | 3.458  | 29.625 |
| R6  | 0.375  | 0.000 | 0.000 | 0.000  | 0.000 | 0.000 | 0.417  | 1.000  | 0.375  | 1.000  | 0.375  | 0.000  | 0.458  | 0.000  | 2.500  | 0.000 | 2.042  | 0.417  | 2.000  | 10.958 |
| R7  | 0.417  | 0.375 | 0.375 | 0.375  | 0.833 | 0.000 | 0.000  | 1.208  | 0.417  | 0.375  | 0.375  | 0.375  | 0.417  | 0.375  | 0.458  | 0.417 | 0.000  | 0.375  | 7.542  |        |
| R8  | 2.458  | 0.000 | 0.000 | 4.167  | 0.375 | 0.375 | 0.000  | 0.000  | 0.000  | 0.958  | 0.000  | 0.000  | 0.429  | 0.000  | 0.000  | 0.000 | 0.875  | 1.333  | 0.417  | 11.387 |
| R9  | 0.958  | 1.375 | 0.417 | 0.000  | 0.417 | 0.417 | 0.792  | 0.000  | 0.000  | 2.542  | 4.167  | 4.125  | 3.500  | 0.875  | 2.417  | 0.417 | 0.917  | 0.375  | 4.625  | 28.333 |
| R10 | 0.875  | 3.167 | 0.375 | 1.417  | 0.000 | 0.000 | 1.833  | 0.458  | 4.083  | 0.000  | 4.000  | 2.958  | 3.500  | 0.375  | 0.000  | 0.375 | 1.417  | 0.000  | 2.958  | 27.792 |
| R11 | 0.375  | 0.000 | 0.375 | 0.000  | 0.000 | 0.417 | 0.000  | 0.000  | 1.500  | 1.458  | 0.000  | 1.458  | 0.417  | 0.375  | 0.000  | 0.000 | 0.375  | 0.000  | 0.000  | 6.750  |
| R12 | 0.375  | 0.833 | 0.417 | 0.417  | 0.000 | 0.417 | 0.417  | 0.000  | 3.417  | 4.542  | 1.042  | 0.000  | 3.917  | 0.417  | 0.375  | 0.000 | 0.375  | 0.000  | 0.375  | 17.333 |
| R13 | 0.833  | 0.458 | 0.000 | 0.917  | 0.000 | 0.000 | 0.000  | 0.000  | 2.500  | 4.167  | 4.000  | 5.000  | 0.000  | 1.417  | 0.000  | 0.000 | 0.000  | 0.000  | 0.000  | 19.292 |
| R14 | 0.000  | 0.000 | 0.000 | 0.000  | 0.000 | 0.417 | 0.000  | 0.375  | 0.000  | 3.500  | 4.125  | 4.583  | 4.583  | 0.000  | 1.208  | 0.000 | 0.000  | 0.000  | 0.000  | 18.792 |
| R15 | 0.000  | 0.000 | 0.000 | 0.000  | 0.000 | 0.000 | 0.417  | 0.375  | 1.167  | 3.958  | 3.708  | 2.458  | 4.417  | 0.375  | 0.000  | 0.000 | 0.833  | 0.375  | 4.625  | 22.708 |
| R16 | 1.500  | 0.000 | 0.500 | 0.000  | 0.000 | 0.000 | 0.917  | 0.000  | 0.375  | 0.000  | 0.000  | 0.375  | 0.875  | 0.375  | 0.375  | 0.000 | 0.000  | 0.417  | 0.000  | 5.708  |
| R17 | 0.000  | 0.000 | 0.458 | 0.000  | 0.000 | 0.417 | 0.375  | 0.000  | 0.500  | 1.042  | 0.000  | 0.458  | 2.958  | 0.417  | 2.083  | 0.000 | 0.000  | 0.000  | 1.875  | 10.583 |
| R18 | 3.083  | 0.000 | 0.375 | 0.375  | 0.375 | 0.792 | 0.000  | 2.417  | 0.000  | 0.375  | 0.417  | 0.792  | 0.000  | 0.375  | 0.417  | 0.000 | 0.417  | 0.000  | 0.375  | 10.583 |
| R19 | 0.000  | 0.000 | 0.000 | 0.375  | 0.000 | 2.375 | 0.458  | 0.000  | 3.042  | 4.125  | 4.167  | 2.375  | 2.500  | 0.000  | 5.000  | 0.000 | 3.042  | 0.000  | 0.000  | 27.458 |
| Sum | 18.500 | 7.792 | 4.125 | 11.542 | 7.250 | 8.167 | 12.000 | 11.250 | 21.500 | 35.958 | 33.000 | 32.375 | 41.875 | 13.804 | 18.833 | 2.875 | 17.167 | 15.333 | 25.625 |        |

**Table 13.** Prominence vector ( $D_i + R_j$ ) and relation vector ( $D_i - R_j$ ) of SSCRs.

| No. | $D_i$  | $R_j$  | $D_i+R_j$ | $D_i-R_j$ |
|-----|--------|--------|-----------|-----------|
| R1  | 1.0806 | 0.6976 | 1.7781    | 0.3830    |
| R2  | 1.0510 | 0.4196 | 1.4706    | 0.6313    |
| R3  | 0.7800 | 0.1840 | 0.9640    | 0.5960    |
| R4  | 0.7244 | 0.4701 | 1.1945    | 0.2543    |
| R5  | 1.2443 | 0.2548 | 1.4991    | 0.9895    |
| R6  | 0.4847 | 0.3432 | 0.8279    | 0.1415    |
| R7  | 0.3288 | 0.4807 | 0.8095    | -0.1518   |
| R8  | 0.4752 | 0.3951 | 0.8703    | 0.0800    |
| R9  | 1.2494 | 1.1235 | 2.3729    | 0.1258    |
| R10 | 1.2093 | 1.7019 | 2.9112    | -0.4927   |
| R11 | 0.3183 | 1.5793 | 1.8976    | -1.2609   |
| R12 | 0.8213 | 1.5348 | 2.3561    | -0.7135   |
| R13 | 0.8601 | 1.8129 | 2.6730    | -0.9527   |
| R14 | 0.8037 | 0.5877 | 1.3914    | 0.2160    |
| R15 | 1.0187 | 0.7982 | 1.8169    | 0.2205    |
| R16 | 0.2489 | 0.1148 | 0.3637    | 0.1341    |
| R17 | 0.4958 | 0.7348 | 1.2306    | -0.2390   |
| R18 | 0.4560 | 0.5076 | 0.9635    | -0.0516   |
| R19 | 1.1904 | 1.1002 | 2.2906    | 0.0902    |

**Table 14.** The comprehensive influence matrix T.

| No. | R1    | R2    | R3    | R4    | R5    | R6    | R7    | R8    | R9    | R10   | R11   | R12   | R13   | R14   | R15   | R16   | R17   | R18   | R19   |
|-----|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| R1  | 0.014 | 0.017 | 0.016 | 0.013 | 0.013 | 0.011 | 0.049 | 0.017 | 0.054 | 0.144 | 0.076 | 0.083 | 0.144 | 0.122 | 0.083 | 0.012 | 0.102 | 0.015 | 0.095 |
| R2  | 0.045 | 0.016 | 0.015 | 0.039 | 0.098 | 0.011 | 0.022 | 0.037 | 0.072 | 0.119 | 0.091 | 0.085 | 0.100 | 0.040 | 0.039 | 0.013 | 0.062 | 0.101 | 0.047 |
| R3  | 0.083 | 0.018 | 0.005 | 0.021 | 0.018 | 0.038 | 0.109 | 0.020 | 0.025 | 0.064 | 0.044 | 0.044 | 0.090 | 0.046 | 0.032 | 0.015 | 0.029 | 0.040 | 0.042 |
| R4  | 0.086 | 0.029 | 0.004 | 0.011 | 0.016 | 0.025 | 0.018 | 0.031 | 0.026 | 0.065 | 0.044 | 0.056 | 0.106 | 0.028 | 0.026 | 0.002 | 0.029 | 0.082 | 0.042 |
| R5  | 0.040 | 0.025 | 0.007 | 0.071 | 0.007 | 0.026 | 0.012 | 0.082 | 0.104 | 0.082 | 0.132 | 0.156 | 0.158 | 0.041 | 0.030 | 0.012 | 0.036 | 0.109 | 0.114 |
| R6  | 0.016 | 0.006 | 0.002 | 0.007 | 0.002 | 0.006 | 0.016 | 0.027 | 0.028 | 0.051 | 0.037 | 0.023 | 0.040 | 0.007 | 0.075 | 0.001 | 0.061 | 0.013 | 0.068 |
| R7  | 0.017 | 0.013 | 0.011 | 0.016 | 0.022 | 0.003 | 0.004 | 0.032 | 0.021 | 0.025 | 0.025 | 0.025 | 0.027 | 0.016 | 0.016 | 0.012 | 0.017 | 0.006 | 0.020 |
| R8  | 0.072 | 0.005 | 0.002 | 0.103 | 0.012 | 0.015 | 0.006 | 0.007 | 0.011 | 0.023 | 0.038 | 0.018 | 0.027 | 0.022 | 0.012 | 0.001 | 0.033 | 0.042 | 0.024 |
| R9  | 0.040 | 0.051 | 0.017 | 0.014 | 0.017 | 0.024 | 0.035 | 0.008 | 0.059 | 0.139 | 0.169 | 0.162 | 0.153 | 0.040 | 0.090 | 0.013 | 0.051 | 0.019 | 0.147 |
| R10 | 0.041 | 0.092 | 0.017 | 0.047 | 0.013 | 0.013 | 0.058 | 0.019 | 0.144 | 0.073 | 0.157 | 0.132 | 0.146 | 0.030 | 0.032 | 0.013 | 0.060 | 0.016 | 0.106 |
| R11 | 0.014 | 0.007 | 0.011 | 0.004 | 0.002 | 0.013 | 0.006 | 0.002 | 0.050 | 0.053 | 0.019 | 0.052 | 0.031 | 0.015 | 0.008 | 0.001 | 0.016 | 0.002 | 0.013 |
| R12 | 0.024 | 0.039 | 0.015 | 0.021 | 0.006 | 0.016 | 0.023 | 0.006 | 0.118 | 0.153 | 0.078 | 0.052 | 0.139 | 0.025 | 0.027 | 0.004 | 0.027 | 0.008 | 0.042 |
| R13 | 0.034 | 0.030 | 0.006 | 0.032 | 0.005 | 0.007 | 0.013 | 0.005 | 0.100 | 0.149 | 0.141 | 0.162 | 0.055 | 0.047 | 0.017 | 0.003 | 0.018 | 0.007 | 0.030 |
| R14 | 0.012 | 0.017 | 0.005 | 0.011 | 0.003 | 0.015 | 0.010 | 0.013 | 0.044 | 0.133 | 0.142 | 0.153 | 0.151 | 0.013 | 0.039 | 0.002 | 0.014 | 0.004 | 0.023 |
| R15 | 0.015 | 0.019 | 0.006 | 0.014 | 0.004 | 0.013 | 0.023 | 0.014 | 0.080 | 0.156 | 0.150 | 0.116 | 0.158 | 0.023 | 0.028 | 0.003 | 0.044 | 0.014 | 0.139 |
| R16 | 0.040 | 0.003 | 0.013 | 0.002 | 0.002 | 0.002 | 0.026 | 0.003 | 0.017 | 0.015 | 0.012 | 0.021 | 0.035 | 0.016 | 0.015 | 0.001 | 0.006 | 0.012 | 0.008 |
| R17 | 0.007 | 0.008 | 0.013 | 0.006 | 0.002 | 0.016 | 0.016 | 0.003 | 0.035 | 0.058 | 0.034 | 0.042 | 0.098 | 0.018 | 0.063 | 0.001 | 0.011 | 0.003 | 0.063 |
| R18 | 0.082 | 0.005 | 0.011 | 0.018 | 0.011 | 0.023 | 0.007 | 0.062 | 0.013 | 0.033 | 0.028 | 0.035 | 0.025 | 0.022 | 0.022 | 0.002 | 0.024 | 0.006 | 0.025 |
| R19 | 0.016 | 0.021 | 0.007 | 0.021 | 0.004 | 0.066 | 0.027 | 0.007 | 0.123 | 0.165 | 0.165 | 0.118 | 0.129 | 0.016 | 0.145 | 0.003 | 0.096 | 0.007 | 0.052 |

$D_i + R_j$  is the centrality, indicating the total degree of influence and the degree of influence of this factor. The larger the centrality value, the stronger is the relationship between this factor and other factors, and the greater is this factor’s importance. Similarly,  $D_i - R_j$  is the degree of cause. If it is positive, it indicates that this factor is the influencing factor. The greater the value, the greater the influence on other factors. If is negative, it indicates that the factor is the affected factor. The smaller the value, the more easily it is affected. A more detailed explanation and discussion of SSCRs are presented in Section 4.2.

4.1.4. Step 4: Obtaining the Correlation of Agility Criteria and the Matrix of the Relationship between SSCRs and Agility Criteria

This process was performed to select 20 agility criteria and 19 SSCRs after step 1 and conduct the GRA expert questionnaire survey. In view of the interdependent nature of

agile capabilities and risks, it will cause the value of the element of the correlation matrix to change, so as to further calculate the grey correlation degree.

1. Construct the incidence matrix between SSCRs and agility criteria. The aim is to determine the correlation between agility and SSCRs; the numerical values 1, 3 and 9 indicate low correlation, moderate correlation, and high correlation, respectively. Table 15 shows the correlation matrix of defuzzification after the eight questionnaires were collected; the arithmetic mean method was used for defuzzification. The correlation matrix is in the middle of the HoQ.
2. Construct the correlation matrix of agility criteria. The aim is to determine interrelationships between agility criteria and to express them in numerical terms; 1, 3 and 9 indicate slight correlation, moderate correlation, and absolute correlation, respectively. This matrix is used as the roof of the HoQ. Table 16 shows the correlation matrix of defuzzification of the eight questionnaires after they were collected; the arithmetic mean method was used for defuzzification.

**Table 15.** The incidence matrix between SSCRs and agility criteria.

| No. | A1   | A2   | A3   | A4   | A5   | A6   | A7   | A8   | A9   | A10  | A11  | A12  | A13  | A14  | A15 | A16  | A17  | A18  | A19  | A20  |
|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|-----|------|------|------|------|------|
| R1  | 9    | 9    | 1.5  | 1    | 1.5  | 1.75 | 1    | 1.5  | 4.5  | 1    | 1    | 2.25 | 1.75 | 1    | 1   | 1.5  | 1    | 4.5  | 1    | 1.5  |
| R2  | 1    | 1    | 1.5  | 6    | 2.5  | 1.5  | 1    | 3    | 1    | 1    | 1    | 1.75 | 2.25 | 1.75 | 1   | 1.5  | 1.75 | 1.75 | 1    | 1    |
| R3  | 5.25 | 5.25 | 1    | 1    | 1    | 1    | 1.75 | 1.75 | 1.75 | 1    | 1    | 1.75 | 1.75 | 1    | 1   | 1.5  | 1    | 1.5  | 1    | 1    |
| R4  | 5.25 | 1.75 | 1.5  | 1    | 1.75 | 1.5  | 1    | 5.25 | 1    | 1.75 | 1    | 1.75 | 1    | 1    | 1   | 1.75 | 1    | 3    | 1.75 | 1    |
| R5  | 1.5  | 1    | 1.5  | 1.5  | 1.75 | 1    | 1    | 1    | 1    | 1    | 1    | 1.75 | 1    | 1    | 1   | 1.75 | 2.5  | 1    | 1    | 1    |
| R6  | 1.75 | 1.5  | 1.75 | 1.5  | 1.75 | 1    | 3    | 3    | 1.75 | 3    | 1.75 | 1    | 1    | 1.5  | 1   | 1    | 1    | 1    | 1    | 1    |
| R7  | 1    | 1    | 1    | 1    | 1    | 1    | 1.75 | 1.75 | 1    | 1    | 1    | 1    | 1    | 1    | 1   | 1    | 1    | 1    | 1    | 1    |
| R8  | 2.25 | 1.75 | 2.5  | 1    | 3    | 5.25 | 6.75 | 3    | 1    | 2.25 | 1.75 | 1    | 2.5  | 2.5  | 1.5 | 1    | 9    | 1    | 3    | 1.75 |
| R9  | 7.5  | 2.5  | 1.75 | 1.5  | 1.75 | 4.5  | 2.5  | 1    | 1.75 | 1.75 | 5.25 | 1    | 1    | 1    | 1   | 2.25 | 1.75 | 1.5  | 1    | 1    |
| R10 | 6.75 | 5.25 | 1    | 5.25 | 1    | 5.25 | 1    | 1    | 1.75 | 1.75 | 9    | 1    | 1    | 1    | 1   | 1.5  | 2.5  | 3    | 1    | 5.25 |
| R11 | 2.5  | 1.75 | 1    | 1    | 1.75 | 2.25 | 1.75 | 1    | 1    | 1    | 6.75 | 1    | 1.75 | 1    | 1   | 5.25 | 1.75 | 1    | 1    | 1.75 |
| R12 | 7.5  | 1    | 1    | 3    | 1    | 3    | 1.5  | 1    | 1    | 1    | 1.75 | 1    | 1.75 | 1    | 1   | 2.25 | 2.5  | 1.75 | 1    | 1.5  |
| R13 | 9    | 7.5  | 1    | 9    | 1    | 9    | 2.25 | 1    | 3    | 1.75 | 1.5  | 1.75 | 1    | 1    | 1   | 1.75 | 1.75 | 9    | 1    | 1.75 |
| R14 | 5.25 | 9    | 1    | 7.5  | 1    | 9    | 1    | 1.5  | 3    | 1    | 1    | 1.75 | 1.75 | 1    | 1   | 1    | 2.25 | 6.75 | 1    | 1    |
| R15 | 1    | 9    | 6.75 | 5.25 | 2.25 | 1.5  | 6.75 | 1.5  | 3    | 2.5  | 1    | 5.25 | 1    | 1    | 1   | 1    | 1    | 1    | 1.5  | 1    |
| R16 | 1.75 | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1.75 | 1    | 1   | 1    | 1    | 1    | 1.5  | 1    |
| R17 | 1    | 9    | 1    | 7.5  | 1    | 7.5  | 1    | 1.75 | 3    | 1    | 2.5  | 1    | 1    | 2.25 | 2.5 | 1    | 1    | 4.5  | 1    | 1.75 |
| R18 | 2.25 | 1    | 3    | 1    | 3    | 1    | 1    | 5.25 | 1    | 1.5  | 1    | 1.75 | 1.5  | 1.75 | 1   | 1    | 1    | 1    | 1    | 1    |
| R19 | 9    | 9    | 1.5  | 1.5  | 2.5  | 1    | 2.25 | 1.75 | 2.25 | 2.25 | 1    | 1.5  | 1    | 9    | 1   | 1    | 1    | 1    | 1    | 1    |

4.1.5. Step 5: Sorting the Agility Criteria Using GRA

1. Calculate the integrated weight of key SSCRs. The integrated weight can be obtained by matrix multiplication of the AHP weight in Table 7 (obtained in Step 2) and the total influence matrix T in Table 14 (obtained in Step 3). The results are shown in Table 17, and it is on the far-right side of the HoQ.

As evident in Table 17, among the SSCRs faced by small and medium-sized enterprises, The results showed that the best SSCRs were R9 (‘disruption or delay in the delivery of goods because of inadequate liquidity and poor financial conditions’), R5 (‘the information system was compromised’), R10 (‘credibility and competence of operators and leaders’), R19 (‘long product lead time’) and R1 (‘product safety and quality’).

2. Calculate the grey correlation degree. The normalized correlation matrix can be obtained by multiplying the matrices in Table 15 with those in Table 16, and it can be used as the original matrix for grey correlation analysis. Equations (13)–(16) are used to obtain the grey correlation degree of key agility criteria, as shown in Table 18. Table 18 is below the HoQ.

**Table 16.** The correlation matrix of agility criteria.

| No. | A1   | A2   | A3   | A4   | A5  | A6  | A7   | A8   | A9   | A10  | A11  | A12  | A13  | A14  | A15  | A16  | A17  | A18  | A19  | A20  |
|-----|------|------|------|------|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| A1  | 10   | 2.25 | 1    | 1    | 1   | 1   | 1    | 1    | 5.25 | 5.25 | 6.75 | 1    | 1.75 | 1    | 1    | 2.25 | 1.75 | 1    | 1    | 1.75 |
| A2  | 2.25 | 10   | 1    | 1    | 1   | 3   | 9    | 2.25 | 9    | 1    | 1    | 9    | 2.25 | 2.25 | 1    | 1    | 1    | 1    | 1    | 1    |
| A3  | 1    | 1    | 10   | 1    | 9   | 1   | 9    | 3    | 1    | 9    | 5.25 | 1.75 | 1    | 5.25 | 1    | 1    | 1    | 1    | 1    | 1.75 |
| A4  | 1    | 1    | 1    | 10   | 1   | 9   | 5.25 | 1.75 | 9    | 1.75 | 3    | 1    | 1    | 1    | 1    | 1    | 9    | 1.5  | 1    | 1    |
| A5  | 1    | 1    | 9    | 1    | 10  | 1   | 7.5  | 1    | 1    | 7.5  | 9    | 1    | 1    | 7.5  | 1    | 1    | 7.5  | 1    | 1    | 1    |
| A6  | 1    | 3    | 1    | 9    | 1   | 10  | 9    | 1    | 1    | 7.5  | 1.5  | 1    | 1    | 7.5  | 1.5  | 1.5  | 7.5  | 1    | 1    | 1    |
| A7  | 1    | 9    | 9    | 5.25 | 7.5 | 9   | 10   | 7.5  | 9    | 9    | 9    | 7.5  | 1    | 9    | 1    | 1    | 1.75 | 1    | 1    | 1    |
| A8  | 1    | 2.25 | 3    | 1.75 | 1   | 1   | 7.5  | 10   | 1.5  | 1    | 1.5  | 1    | 6.75 | 6.75 | 1    | 1    | 1    | 1    | 1    | 1    |
| A9  | 5.25 | 9    | 1    | 9    | 1   | 1   | 9    | 1.5  | 10   | 1.75 | 1    | 2.25 | 1.75 | 6.75 | 1    | 1    | 1.75 | 1.75 | 1    | 1    |
| A10 | 5.25 | 1    | 9    | 1.75 | 7.5 | 7.5 | 9    | 1    | 1.75 | 10   | 1    | 1.75 | 1    | 1.75 | 1    | 1    | 1    | 1    | 1    | 1    |
| A11 | 6.75 | 1    | 5.25 | 3    | 9   | 1.5 | 9    | 1.5  | 1    | 1    | 10   | 4.5  | 1    | 3    | 1    | 1    | 1    | 1    | 1    | 2.25 |
| A12 | 1    | 9    | 1.75 | 1    | 1   | 1   | 7.5  | 1    | 2.25 | 1.75 | 4.5  | 10   | 4.5  | 1    | 1    | 1    | 2.5  | 1    | 1    | 1    |
| A13 | 1.75 | 2.25 | 1    | 1    | 1   | 1   | 1    | 6.75 | 1.75 | 1    | 1    | 4.5  | 10   | 1    | 1    | 5.25 | 1.75 | 5.25 | 1    | 9    |
| A14 | 1    | 2.25 | 5.25 | 1    | 7.5 | 7.5 | 9    | 6.75 | 6.75 | 1.75 | 3    | 1    | 1    | 10   | 2.25 | 1    | 2.25 | 3    | 9    | 1    |
| A15 | 1    | 1    | 1    | 1    | 1   | 1.5 | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 2.25 | 10   | 1    | 1    | 1    | 3    | 1    |
| A16 | 2.25 | 1    | 1    | 1    | 1   | 1.5 | 1    | 1    | 1    | 1    | 1    | 1    | 5.25 | 1    | 1    | 10   | 1    | 1.5  | 1.75 | 2.5  |
| A17 | 1.75 | 1    | 1    | 9    | 7.5 | 7.5 | 1.75 | 1    | 1.75 | 1    | 1    | 2.5  | 1.75 | 2.25 | 1    | 1    | 10   | 7.5  | 2.5  | 1    |
| A18 | 1    | 1    | 1    | 1.5  | 1   | 1   | 1    | 1    | 1.75 | 1    | 1    | 1    | 5.25 | 3    | 1    | 1.5  | 7.5  | 10   | 1.75 | 1    |
| A19 | 1    | 1    | 1    | 1    | 1   | 1   | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 9    | 3    | 1.75 | 2.5  | 1.75 | 10   | 1    |
| A20 | 1.75 | 1    | 1.75 | 1    | 1   | 1   | 1    | 1    | 1    | 1    | 2.25 | 1    | 9    | 1    | 1    | 2.5  | 1    | 1    | 1    | 10   |

**Table 17.** Integrated weights of key SSCRs.

| No. | Sustainable Supply Chain Risks   | Integrated Weight |
|-----|--|-------------------|
| R1  | Product safety and quality   | 0.06398           |
| R2  | Staff information was leaked   | 0.05759           |
| R3  | Illegal operation by an employee   | 0.04347           |
| R4  | Inadequate information security and information leakage  | 0.04172           |
| R5  | Information system instability   | 0.07186           |
| R6  | Bullwhip effect  | 0.02526           |
| R7  | Man-made accidents   | 0.01827           |
| R8  | IT and information sharing   | 0.02589           |
| R9  | Disruption or delay in the delivery of goods because of inadequate liquidity and poor financial conditions | 0.07345           |
| R10 | Credibility and competence of operators and leaders  | 0.07053           |
| R11 | The company’s financial management and control process, poor management policies                           | 0.02128           |
| R12 | The company’s market share has decreased   | 0.04623           |
| R13 | Brand reputation is damaged, corporate culture is consistent   | 0.05877           |
| R14 | Reductions in poor-quality materials have resulted in termination of supply                                | 0.04954           |
| R15 | Failure to deliver on time, affecting customer expectations  | 0.05707           |
| R16 | Working conditions at production centers are poor  | 0.01614           |
| R17 | Supply chain accidents, delivery delays and a decline in the company’s reputation                          | 0.02787           |
| R18 | Data missing, unable to obtain part of the information   | 0.02783           |
| R19 | Long product lead time   | 0.06716           |

Finally, draw the HoQ, which is shown in Figure 4. The results showed that the best agility criterion were A1 (‘production and sales capability’), A11 (‘quick decision/strategic flexibility’), A15 (‘electronic shipment of finished products to control shipment operations’), A10 (‘supplier on-time delivery rates’) and A16 (‘cost minimization’), in this order.

**Table 18.** Grey correlation degree and sorting of agility criteria.

| No. | Agility Criteria  | Grey Correlation Degree | Sort |
|-----|---|-------------------------|------|
| A1  | Production and sales capability   | 0.501510                | 1    |
| A11 | Quick decision/strategic flexibility  | 0.493313                | 2    |
| A15 | Electronic shipment of finished products to control shipment operations                                       | 0.490280                | 3    |
| A10 | Supplier on-time delivery rates   | 0.481995                | 4    |
| A16 | Cost minimization   | 0.476939                | 5    |
| A9  | Improve customer service  | 0.476330                | 6    |
| A13 | Quality improvement   | 0.471854                | 7    |
| A7  | Quick customer response   | 0.469493                | 8    |
| A8  | Accuracy of data  | 0.452583                | 9    |
| A2  | Improve customer satisfaction   | 0.448352                | 10   |
| A6  | Establish long-term cooperation and trust relationship with partners  | 0.445881                | 11   |
| A14 | Reduce delivery time, that is, delivery time control  | 0.445472                | 12   |
| A4  | Establish partnerships with other enterprises/implement win-win cooperation strategies with suppliers         | 0.431746                | 13   |
| A20 | Manage the core competitiveness of the enterprise   | 0.426336                | 14   |
| A12 | Improve delivery reliability  | 0.425416                | 15   |
| A18 | Enhance brand value   | 0.417741                | 16   |
| A17 | Actively build an information sharing platform with partners  | 0.417253                | 17   |
| A3  | Shorten development cycle/enhance product innovation by improving R&D capability/new product launch frequency | 0.412224                | 18   |
| A5  | Reduce manufacturing lead time/lead time for quick response/synchronous engineering                           | 0.407210                | 19   |
| A19 | Adopt e-business  | 0.406884                | 20   |

#### 4.2. Implications and Recommendations

In this study, the integrated framework based on QFD-MCDM transformed the SSCRs in the EMSC into agility criteria and provided a risk mitigation tool for establishing a sustainable supply chain. This decision-making framework can provide the multinational manufacturing industry with agile solutions to reduce SSCRs. In particular, it can help manufacturers plan strategies in advance to improve enterprise agility and reduce risks.

The results of the analysis of the internal dependence/causality of the risks of a sustainable supply chain are discussed here. According to the data set  $D_i + R_j$  in Table 13, the SSCR with the largest value is “credibility and competence of operators and leaders (R10)”, indicating that this factor has the highest centrality, the highest relationship strength and the highest importance among all factors. Managers and leaders are not only the organizers and commanders of enterprises’ production and operation activities, but also specialized talents engaged in enterprise economic work. Their reputation and ability directly affect the reputation and production and operation of enterprises, and play an important role in the future development of enterprises. Therefore, managers and leaders should pay attention to improving their own capabilities.

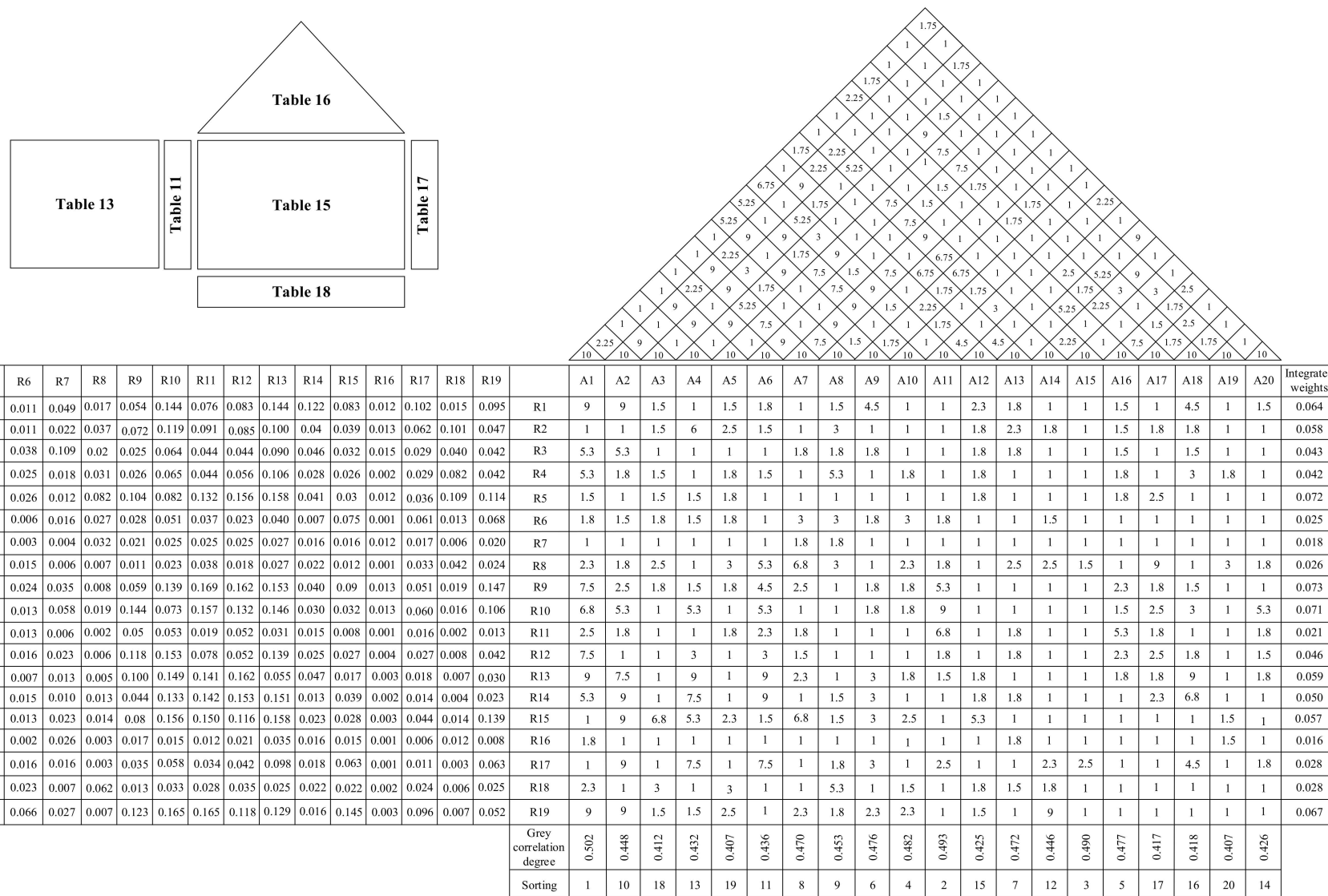


Figure 4. The HoQ results.

According to the data set  $D_i - R_j$ , SSCRs can be divided into two groups: when  $D_i - R_j$  is positive, it is called the causal group, and when  $D_i - R_j$  is negative, it is called the affected group. The 12 SSCRs in the causal group are important for business managers, for the development of risk mitigation strategies, because they tend to influence other factors and thereby influence the overall performance of the system. According to  $D_i - R_j$ , the largest value is information system instability (R5), which needs special attention of enterprise managers. If an enterprise's information system is unstable (R5), a large amount of production management information will be leaked, deleted or modified, seriously affecting the enterprise's production activities and managers' strategic decisions. Therefore, the enterprise should strengthen the security of the information system.

In the results of the importance of SSCRs, Table 17 shows that the first five types of SSCRs are 'disruption or delay in the delivery of goods because of inadequate liquidity and poor financial conditions' (R9), 'information system instability' (R5), 'credibility and competence of operators and leaders' (R10), 'long product lead time' (R19) and 'product safety and quality' (R1). Ranked second and third in the sorting of the importance of SSCRs were the main reason (R5) and the centre of the highest factor (R10), and the DEMATEL analysis results are consistent with these results. This situation shows that 'information systems instability' and 'credibility and competence of operators and leaders' are major challenges for the enterprise. Managers should strengthen these two aspects for risk prevention.

An important task of business managers is to solve the problem of goods being interrupted or delayed due to lack of supply liquidity and poor financial conditions. Lack of liquidity or disruption in supply and the poor financial condition of the enterprise can lead to lower revenue and sales, which can impact labor utilization and cause long delivery delays [175]. Delivery disruptions or delays can expose a company to default risk and stock shortage risk as well as huge economic losses, affect a company's competitive positioning in the market, and even lead to the suspension of other activities in the supply chain [176,177]. Hence, companies should pay attention to the risk of cargo disruptions and delays.

Second, 'product safety and quality' (R1) is the cornerstone and fundamental of an enterprise's development and plays an important role in the sustainable development of electronics manufacturing [178]. If the quality of products is not up to standard, the delivery of goods will be interrupted or delayed, which will prolong the delivery time of products and affect the stable operation of the supply chain. With the development of electronic technology, environmental sustainability and green have become the main theme of product manufacturing, and an increasing number of enterprises are focusing on product safety to promote the development of circular economy [178].

Finally, long product lead times (R19) increase production and operating costs, while short product lead times help companies avoid disruptions or delays and improve their market share and competitiveness. Product delivery time control requires enterprises to manage product design, manufacturing, inventory, delivery and other aspects. It can shorten the response cycle of the supply chain and help achieve the agile operation of the supply chain.

SCA is a mitigation tool for SSCRs, and Table 18 shows specific agile measures to prevent risks. The top five agility criteria are 'production and sales capability' (A1), 'quick decision/strategic flexibility' (A11), 'electronic shipment of finished products to control shipment operations' (A15), 'supplier on-time delivery rates' (A10) and 'cost minimization' (A16). To address the above five SSCRs, the case company should first improve its production and sales capabilities (A1). This can help the case company to complete product delivery on time, ensure product safety and quality, generate huge profits for the enterprise, maintain the financial status of the enterprise, and prevent interruption or delay of goods.

Case companies can improve their capability for quick decision/strategic flexibility (A11) to help managers to make reasonable and effective decisions quickly and to avoid information system instability (R5) or reduce the loss caused by system invasion. They can also drive their managers, to improve credibility and ability (R10). As the environment



continues to change and as various factors that influence decisions change, strategic flexibility becomes particularly important as a means of managing and controlling risks and achieving business sustainability, as it enables organizations to be more innovative in their processes, products and services [179].

The improved ability to ship finished products electronically in order to control the shipment operation (A15) played an important role in helping the case company overcome R9 and R19. Electronic delivery of finished products ensures the smooth delivery of finished products out of storage, saves transportation time, delivers goods to customers on time, and improves the overall customer satisfaction.

When purchasing raw materials, the case company should pay attention to the supplier's on-time delivery rates (A10). If the supplier's on-time delivery rate is too low, the lack of raw material procurement will seriously affect product production and subsequently affect the normal operation and performance of the whole company. Therefore, a high supply rate can maintain the fluency of the supply chain and the financial status of the enterprise.

Finally, cost minimization (A16) can help the case company save money and avoid unnecessary wastage. The implementation of a cost minimization strategy can help optimize product design, obtain a price advantage on the product and better meet the needs of consumers. The case company can also improve the customer service level (A9), quality (A13), rapid customer response ability (A7), data accuracy (A8) and other criteria to prevent SSCRs and to promote the sustainability of the EMSC.

The Pareto effect, also known as the 80/20 rule, states that about 80% of the effects come from 20% of the causes, that is, a small number of causes have a big impact. This means that larger outcomes can be achieved by addressing the few causes or risks that are critical [180]. In the case of limited resources, the Pareto effect can be applied to the results of the QFD-MCDM framework, as shown in Figure 5. Multinational electronics manufacturers can reduce the most important SSCRs by reinforcing the most important agility guidelines. Once the first five agility criteria are adjusted, other SSCRs will also be alleviated to a certain extent, thereby improving the entire supply chain level. On this basis, as electronics manufacturers continue to invest time and money to improve the SCA, the SSCRs will be gradually reduced and finally, the expected goal of manufacturing system will be achieved.

Recent mitigation measures on SSCRs mainly focus on supply chain elasticity. As an important capability of supply chain elasticity, agility plays an important role in mitigating SSCRs. As mentioned in Section 2.3, agility has been identified as an important risk mitigation tool. However, empirical studies on the mitigation of SSCRs using SCA are still scarce, especially in the multinational electronic manufacturing industry. This study enriches the related concepts in the field of supply chain risk management, and it also provides some reference value through which other scholars can discuss the relationship between agility and risk.

In recent years, scholars have combined different MCDM methods with QFD to explore different fields such as the circular economy [151], sustainable product design [181], risk mitigation in the power sector [150], the quality characteristics of manufacturing enterprises [182], and fashion supply chain risk mitigation [15]. Although different MCDM methods have been combined with QFD in these studies, no mode has been found to combine FDM, AHP, DEMATEL and GRA with QFD. Secondly, this study innovatively uses QFD-MCDM to explore the relationship between SSCR and SCA. In addition, this study also applies QFD-MCDM to multinational electronic manufacturing enterprises, providing empirical research that finds agile solutions that reduce the risk of sustainable supply chains. Therefore, the method proposed in this study, as well as the content and application of the method, are unique.

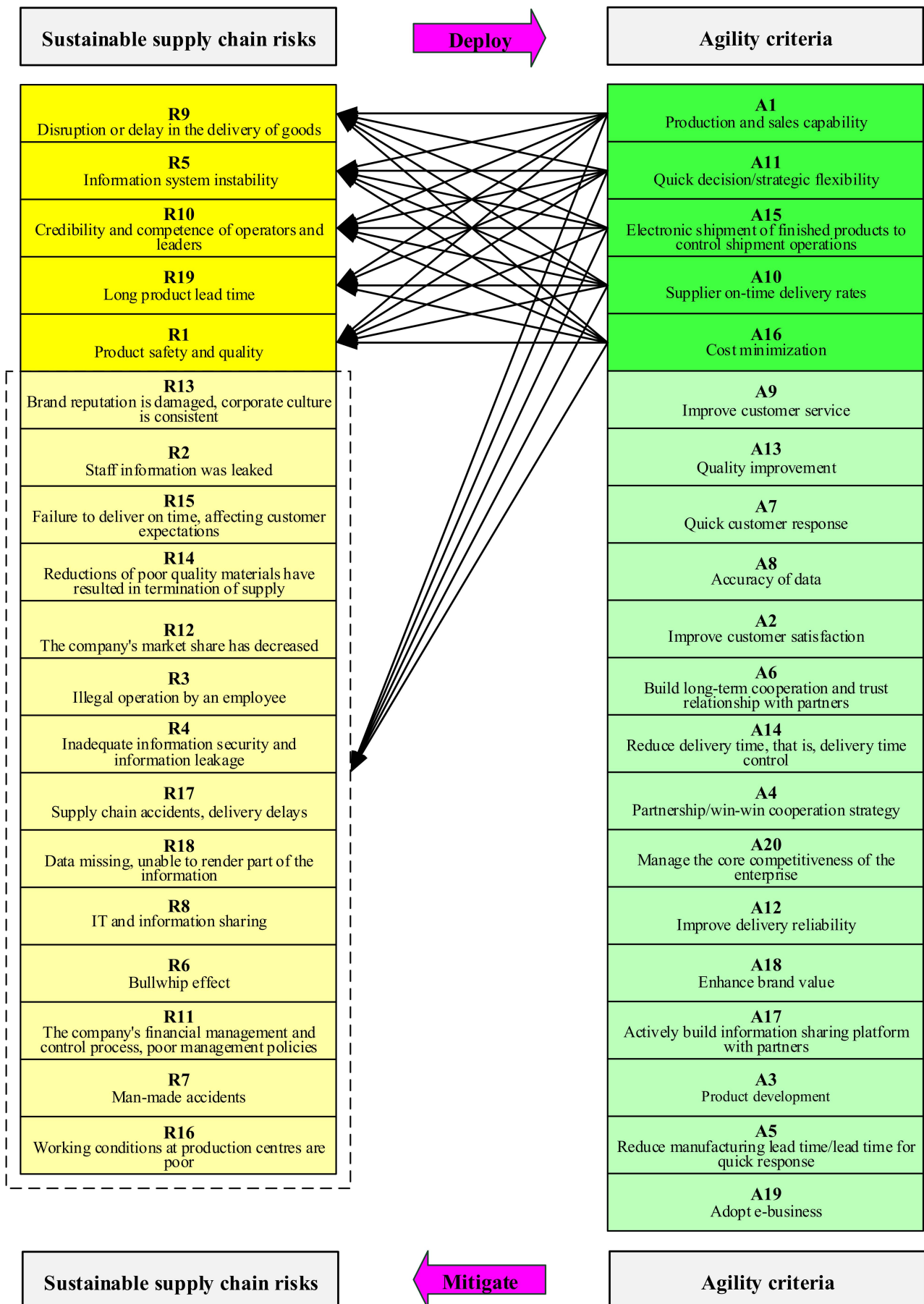


Figure 5. Agility-enhancing solutions to mitigate SSCRs in the EMSC.

When using the QFD-MCDM framework, it should be noted that there is no need to use too much software when processing the data. At the same time, it should be noted that each method's analysis steps should be clear so that a large number of data operations can be carried out. For example, the weight calculated by AHP is combined with the SSCR autocorrelation matrix to obtain the integration weight. The correlation matrix of the SSCRs and agility criteria as well as the autocorrelation matrices of the agility criteria are combined as the initial matrix for GRA analysis. Attention should be paid to remind the experts to fill in the questionnaire scientifically and truthfully to avoid repeating the questionnaire. For example, consistency requirements should be met during AHP analysis.

In this study, AHP was used to solve multi-person, multi-attribute and multi-cycle problems with hierarchical complex structures. SSCR has two levels of indicators, and AHP can be used to clearly obtain the priority scale of each level of indicators. The results are improved. DEMATEL was used in this study to explore the binary relationship of key SSCRs. Therefore, this study first used AHP to calculate the priority of the first and second level SSCR indicators and then used DEMATEL to calculate the internal dependence. In this way, this study can better understand the importance ranking of agility criteria and SSCRs and provide managers with risk mitigation programs. Therefore, this study asserts that the framework cannot be simplified.

## 5. Conclusions

In this study, a QFD-MCDM integrated framework was used to determine the relationship between the identified SSCRs and between SSCRs and agility criteria, apart from being used to ascertain the importance of SSCRs and agility criteria. This study makes an important contribution towards the improvement of the agile capability of EMSCs, which can reduce SSCRs. The following results were obtained through examples.

- The top five SSCRs affecting the EMSC were 'disruption or delay in the delivery of goods because of inadequate liquidity and poor financial conditions', 'information system instability', 'credibility and competence of operators and leaders', 'long product lead time' and 'product safety and quality'.
- The top five agility criteria affecting the EMSC were 'production and sales capability', 'quick decision making/strategic flexibility', 'electronic shipment of finished products to control shipment operations', 'supplier on-time delivery rates' and 'cost minimization'.

The results of this study have certain reference value for managers of the multinational electronics manufacturing industry to improve their agile ability and identify and mitigate SSCRs.

In addition, this study has made a significant contribution to research in multinational electronics manufacturing field.

Firstly, the FDM-AHP-DEMATEL-GRA integration method based on the QFD framework is proposed. The HoQ model is constructed by the QFD-MCDM method to relate the SSCRs and the agility criteria, and the model is used to support decision-making of the multinational electronics manufacturing industry.

Secondly, through the integrated framework, the relationship between the SSCRs and the agility criteria and their respective internal dependence were investigated to provide agility solutions for SSCRs to multinational EMSCs.

Finally, the framework can guide managers of multinational electronic manufacturing enterprises on how to enhance or strengthen the SCA ability to eliminate or mitigate SSCRs so as to make the supply chain more resilient and efficient.

The QFD-MCDM framework can be implemented not only in EMSCs, but also in other industrial areas in other regions. However, the application of the framework in different contexts produces different results, as each supply chain is characterized by the economic, social, political, natural, and geographical factors in which it operates [183]. Although the proposed framework can be applied to other industries, different industries have their own unique SSCRs and agility criteria, and evaluation indicators should be redefined. The framework can also be connected with other tools, such as the IT, IT of Things and big data

to help monitor, plan and optimize supply chains in real time. This study only evaluated SSCRs and agility criteria. Other variables can be added in the future to establish a more comprehensive and deeper sustainable supply chain.

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## Abbreviations

|   |         |
|---|---------|
| Electronic manufacturing supply chain           | EMSC    |
| Sustainable supply chain risk                   | SSCR    |
| Supply chain agility                            | SCA     |
| Multicriteria decision-making                   | MCDM    |
| Quality function deployment                     | QFD     |
| Houses of quality                               | HoQ     |
| Fuzzy Delphi method                             | FDM     |
| Analytic hierarchy process                      | AHP     |
| Decision making trial and evaluation laboratory | DEMATEL |
| Grey relational analysis                        | GRA     |



Table A1. Cont.

| Sustainable Supply Chain Risks (SSCRs)     |   | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 |  |   |   |
|--|---|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|--|---|---|
| Suppliers material supply                  | Cooperation risk, breach of commitment  |   | • |   | • |   |   |   |   | • | •  | •  |    |    | •  | •  |    |    | •  |    | •  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |  |   |   |
|  | Failure of key suppliers  |   |   |   | • |   |   |   |   |   |    | •  | •  | •  | •  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |  |   |   |
|  | Limited green suppliers   |   |   |   | • |   |   |   |   | • |    | •  |    |    |    |    |    |    |    |    |    |    | •  | •  | •  |    | •  | •  | •  | •  | •  | •  |    |    |    |    |    |    |  |   |   |
|  | Supplier capability and reliability   |   |   |   |   |   | • |   | • |   |    |    |    | •  |    | •  |    |    | •  | •  |    |    |    | •  | •  |    | •  |    | •  | •  | •  |    |    | •  |    | •  |    |    |  | • |   |
|  | Supplier dependence and production delays   |   |   |   |   |   |   |   | • |   |    |    |    |    |    |    |    |    |    |    |    |    |    | •  | •  | •  | •  |    |    |    | •  |    |    | •  |    | •  |    |    |  |   |   |
|  | The supplier reassigned the goods for delay   |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    | •  | •  |    | •  |    | •  | •  | •  | •  |    | •  | •  |    |    |    |  |   | • |
|  | Disruption or delay of goods due to inadequate supply liquidity and poor financial conditions |   | • |   | • |   | • | • |   |   |    |    |    |    | •  |    |    |    |    | •  |    |    |    |    |    |    |    |    |    | •  | •  | •  | •  |    |    | •  |    | •  |  |   | • |
|  | The company's market share has decreased  |   |   |   |   |   |   |   |   |   | •  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |  |   |   |
|  | Reductions in poor-quality materials have resulted in termination of supply                   |   | • | • |   |   | • |   |   |   | •  |    |    | •  |    | •  |    |    |    |    |    |    |    |    |    | •  |    | •  | •  | •  |    | •  | •  |    |    | •  |    |    |  |   |   |
|  | Risk of material orders in delivery   |   |   |   | • |   |   |   | • |   |    |    | •  |    | •  | •  | •  | •  | •  | •  | •  | •  | •  |    |    | •  |    |    |    |    |    |    |    | •  |    |    |    |    |  |   |   |
|  | Supplier product quality supervision  |   |   |   | • |   | • |   |   |   |    |    |    |    | •  |    | •  |    |    |    |    |    |    | •  |    | •  |    | •  |    |    |    |    |    |    |    |    |    |    |  |   |   |
|  | Single procurement policy   |   |   |   |   |   |   |   |   |   |    |    |    |    | •  |    | •  |    |    |    |    |    |    | •  | •  |    | •  |    |    | •  | •  |    | •  | •  |    | •  | •  |    |  |   | • |
|  | Fluctuation of purchase price   |   |   | • |   |   | • |   | • | • | •  |    |    | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  |    |    |    |    |    |  |   |   |
|  | Meet demand and reduce inventory  |   | • |   |   |   |   |   | • |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |  |   |   |
|  | Raw material shortage, availability   |   |   |   |   |   |   |   |   |   |    |    | •  |    | •  |    |    |    |    |    |    |    | •  |    |    |    |    |    |    |    |    |    |    |    |    |    | •  |    |  |   | • |
|  | Supplies are out of stock due to interruption of source                                       |   |   |   |   |   |   |   |   |   |    |    | •  | •  |    | •  |    |    |    |    |    |    |    | •  | •  | •  | •  |    |    | •  | •  |    |    | •  | •  |    | •  | •  |  |   | • |
| Human resource dimensions                  | External human attack, error  |   | • |   |   |   |   | • | • |   |    |    |    |    |    | •  | •  |    |    |    |    |    | •  | •  |    | •  | •  |    |    |    |    |    | •  | •  | •  |    |    |    |  |   |   |
|  | Insurrection, war terrorism   |   |   |   | • |   |   |   |   |   |    | •  |    |    |    | •  |    |    |    |    |    |    |    | •  |    |    |    |    |    |    |    |    |    |    |    |    | •  |    |  |   |   |
|  | Man-made accidents  |   |   |   |   |   |   |   | • |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    | •  |    |    |    |    |    |    |    |    |    |    | •  | •  |    |  |   |   |
|  | The labor dispute led to a strike   |   |   |   | • |   |   | • |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | •  |    |    |    |    |    |    |    |    |    |    |    |    |  |   |   |
|  | Child labor, forced labor   |   |   |   |   |   |   |   |   |   |    | •  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |  |   |   |
|  | Omit supervision during homework  |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    | •  | •  | •  | •  |    |    | •  | •  | •  | •  |    | •  | •  | •  | •  |  | • |   |
|  | Employee's illegal operation  |   |   |   | • |   |   | • |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | •  |    | •  |    |    | •  |    | •  |    | •  |    |    |    |  |   | • |
|  | The staff information was leaked  |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | •  |    |    |    |    |    |    |    |    |    | •  |    |    |  |   |   |
|  | People are not skilled, the operation is wrong  |   | • | • |   |   | • |   |   |   |    |    | •  | •  |    |    |    |    |    |    |    |    |    | •  |    |    | •  | •  |    | •  | •  | •  | •  | •  | •  |    | •  | •  |  | • | • |
|  | Labour is not being used efficiently  |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    | •  | •  |    |    |    |    |    | •  |    | •  | •  |    | •  | •  |    |  |   | • |
|  | Credibility and competence of operators and leaders   |   | • | • |   |   | • |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    | •  | •  |    |    |    |    |    |    |    |    |    |    |    |    |    |  |   |   |
|  | High level management involvement is low  |   |   |   |   |   | • |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |  |   |   |
|  | Improper organizational and management skills   |   |   |   |   |   | • |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    | •  |    |    | •  |    |    | •  | •  |    | •  | •  |    | •  | •  |  |   |   |
|  | Misstaffing   |   |   | • |   |   | • |   |   |   |    |    |    |    | •  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |  |   |   |
| Inadequate personnel training and guidance |   |   |   |   |   | • |   |   |   |   |    |    |    |    | •  |    |    |    |    |    |    |    |    | •  | •  |    |    |    |    | •  |    |    | •  |    | •  |    |    |    |  |   | • |

Table A1. Cont.

| Sustainable Supply Chain Risks (SSCRs)   |  | 1  | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 |   |   |   |   |
|--|--|--|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|
| Enterprise interior and equipment aspect | Information equipment failure  |  |   |   | • | • |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    | •  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |
|  | Inadequate information security and leakage  |  |   |   | • |   |   |   |   |   |    |    |    |    |    |    | •  | •  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |
|  | Information system instability   |  |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | • |   |   |   |
|  | Insufficient information method concepts and tools   |  |   |   |   | • |   | • |   |   |    |    |    |    |    |    |    |    |    |    |    | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | • |   |   |   |
|  | Availability and accuracy of information   |  |   | • |   |   | • |   |   |   |    |    | •  |    |    |    |    |    |    | •  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |
|  | Risk factors for information transmission  |  |   | • |   |   |   |   |   | • |    |    |    |    |    |    |    |    |    | •  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |
|  | IT and information sharing risks   |  |   |   |   |   |   |   |   |   | •  |    | •  | •  | •  |    | •  |    | •  |    | •  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |
|  | Risk awareness of the enterprise   |  |   |   | • |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |
|  | Reasons for delay in delivery due to difficulties in changing equipment to production mode |  |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | •  |    |    |    |    | •  |    | •  |    |    |    |    |   | • |   |   |
|  | Technical change or malfunction of equipment   |  |   | • | • | • |   | • |   |   | •  |    | •  | •  |    | •  | •  |    |    | •  | •  |    |    |    |    | •  | •  | •  |    | •  | •  | •  | •  | •  | •  | •  | •  | •  | • | • | • |   |
|  | Improper equipment selection and management  |  |   |   | • |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |
|  | Degree of process informatization  |  | • |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |
|  | Production process, technology standard degree   |  | • | • | • |   |   |   |   |   |    |    |    |    |    | •  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |
|  | Inappropriate/unavailable test method  |  |   |   | • |   | • |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |
|  | Change the IT system and failure   |  | • |   | • |   | • |   |   |   |    |    |    |    |    |    |    | •  |    | •  |    |    |    | •  | •  |    | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | • | • | • | • |
|  | Supply chain accidents, delivery delays and a drop in the company's reputation             |  |   | • |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |
|  | Data missing, unable to render part of the information                                     |  |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    | •  | •  |    |    |    |    |    | •  | •  |    |    | •  |    |    |    |   |   | • |   |
|  | The company's financial processing and control process, management policy errors           |  |   |   |   | • | • | • | • |   |    |    |    | •  |    | •  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |
|  | Inadequate ability to predict risks  |  |   |   | • |   |   | • |   |   |    |    | •  |    |    | •  | •  | •  |    |    |    |    |    | •  | •  |    | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | • | • | • | • |
|  | Changes in Shareholder Structure   |  |   |   |   | • | • |   |   |   |    |    |    |    |    |    |    |    |    | •  |    |    |    |    |    | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | •  | • | • | • | • |
|  | Brand reputation is damaged, corporate culture is consistent                               |  |   |   |   |   |   |   |   |   | •  |    |    |    |    |    |    |    |    | •  |    |    |    |    |    |    | •  |    |    |    |    |    | •  | •  |    |    |    | •  | • | • | • | • |
|  | Ineffective strategic public relations performance   |  |   |   |   | • |   |   |   |   |    |    |    | •  |    |    |    |    |    | •  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |
|  | Customer relations are not good  |  | • |   | • |   | • |   |   |   |    |    | •  | •  |    | •  |    |    |    |    |    |    |    | •  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |
|  | Failure to respond to preferences  |  |   | • |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |
|  | The bullwhip effect  |  |   |   | • |   |   |   |   |   |    |    |    | •  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |
|  | Scholars   | 1: Cai et al. (2020) [67]; 2: Syed et al. (2019) [9]; 3: Deng et al. (2019) [61]; 4: Rostamzadeh et al. (2018) [53]; 5: Valanarasu et al. (2018) [68]; 6: Gautam et al. (2018) [69]; 7: Qazi et al. (2018) [70]; 8: Helmi et al. (2017) [71]; 9: Song et al. (2016) [10]; 10: Giannakis et al. (2016) [72]; 11: Dong et al. (2016) [73]; 12: Mangla et al. (2015) [74]; 13: Guertler (2015) [75]; 14: Aqlan et al. (2015) [76]; 15: Lavastre et al. (2014) [77]; 16: Badea et al. (2014) [78]; 17: Zhang and Cheng (2014) [79]; 18: Sentia et al. (2013) [80]; 19: Wang et al. (2012) [81]; 20: Sofyaloglu et al. (2012) [82]; 21: Tang et al. (2011) [83]; 22: Isaksson and Seifert (2016) [84]; 23: Dominguez-Bello et al. (2016) [85]; 24: Koblen and Škúrková (2015) [86]; 25: Mohammaddust et al. (2015) [87]; 26: Song et al. (2015) [88]; 27: Ouyang et al. (2015) [89]; 28: Mackelprang and Malhotra. (2015) [90]; 29: Cheng et al. (2015) [91]; 30: Cao et al. (2014) [92]; 31: Alhawari et al. (2012) [93]; 32: Jereb et al. (2012) [94]; 33: Thun and Hoening (2009) [95]; 34: Wagner and Bode (2008) [96]; 35: Jüttner et al. (2003) [97]; 36: Van Landeghem and Vanmaele (2002) [98]; 37: Christopher and Lee (2001) [99] |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |





Table A2. Cont.

| Agility Criteria for Supply Chain  |   | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |   |
|--|---|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|---|
| Customer relationship  | Reduce delivery time/delivery time control  |   | • |   | • | • | • |   | • |   |    | •  | •  | •  |    |    | •  | •  | •  |    | •  |   |
|  | Rapid new product launch/increase the frequency of new product introduction to market   |   |   |   | • | • | • |   |   |   |    |    |    |    |    |    | •  |    |    | •  | •  |   |
|  | Improve customer service  |   | • |   |   |   | • | • |   |   |    |    |    |    | •  |    |    |    |    |    |    | • |
|  | Use order-driven rather than forecast-driven  |   |   |   |   | • |   |   |   |   |    | •  |    |    |    |    |    |    |    |    |    |   |
|  | Provide customized products   |   |   |   |   | • | • | • |   |   |    |    |    |    |    |    | •  | •  | •  | •  |    | • |
|  | Quick customer response   |   | • | • | • |   | • |   | • |   | •  | •  | •  |    |    |    |    | •  | •  |    | •  |   |
|  | Improve delivery reliability  |   |   |   | • |   | • |   | • |   |    |    | •  | •  |    | •  |    |    |    |    |    | • |
|  | Provide customer satisfaction   |   |   |   |   |   | • |   |   |   |    | •  | •  | •  |    |    |    |    | •  | •  |    | • |
|  | Provide customers with high value added products  |   |   |   |   | • |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |   |
|  | Design user-friendly/socially compliant products  |   |   |   |   |   |   |   |   |   | •  |    |    |    |    |    | •  |    |    |    |    |   |
| Manufacturing technology capability                                      | Develop flexible production technology  |   |   | • |   |   |   |   |   |   | •  |    |    |    |    |    |    |    |    |    |    |   |
|  | Make flexible products/reduce the complexity of the product design process  | • |   | • | • |   |   |   |   |   | •  |    |    |    |    |    | •  |    |    |    |    | • |
|  | Set up a virtual enterprise   |   |   | • | • | • |   |   |   | • | •  | •  |    | •  |    |    |    |    | •  |    |    |   |
|  | Reduce facility setup and switching time and increase the production quantity of products   |   |   |   |   | • | • |   |   |   |    |    |    |    |    | •  |    |    |    |    |    | • |
|  | Raise awareness of technology and information technology  |   |   | • | • |   |   |   |   |   |    |    |    |    |    | •  |    |    |    |    |    |   |
|  | Introduce appropriate information technology and incorporate new hardware, software and new products                                    |   |   | • | • |   |   |   | • | • |    |    |    |    |    | •  |    |    |    | •  |    |   |
|  | Shorten manufacturing lead time/shorten lead time quick response/implement synchronous engineering                                      |   |   |   | • |   |   |   | • | • | •  |    |    |    |    |    |    | •  |    | •  |    | • |
|  | Shorten the development cycle time/enhance the research and development ability of innovative products/launch frequency of new products | • | • |   |   | • | • | • | • | • | •  |    |    |    |    |    |    | •  | •  |    |    | • |
|  | Reduce production time for new products   |   |   |   |   | • |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    | • |
|  | Manufacturing flexibility/manufacturing flexibility/agile manufacturing   |   |   |   |   | • |   |   | • |   | •  |    |    |    |    |    |    | •  |    |    |    |   |
| Product greenness/product life cycle                                     |   |   |   |   |   |   |   | • |   |   |    |    |    |    |    |    | •  |    |    |    |    |   |
| Improve logistics capability/purchasing capability/build agile logistics |   |   |   |   |   | • |   |   |   |   |    |    |    |    |    |    |    |    | •  |    |    |   |
| Quality improvement  | •   | • |   | • | • | • |   | • |   | • | •  |    | •  | •  |    | •  | •  | •  | •  |    |    |   |

Table A2. Cont.

| Agility Criteria for Supply Chain    |   | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|--------------------------------------|---|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|
| Organization and team management     | Distributed Decision Models   |   |   |   | • |   |   |   |   | • | •  |    |    |    | •  |    |    | •  | •  |    |    |
|                                      | Manage the core competitiveness of the enterprise   |   |   |   |   | • |   |   |   |   | •  |    |    |    |    |    |    |    | •  |    |    |
|                                      | Continuously cultivate multi-skilled and flexible employees and improve their working ability   | • |   |   |   | • |   |   |   |   | •  |    | •  |    | •  |    |    |    | •  |    |    |
|                                      | Build a culture that can change with The Times  |   |   |   |   |   |   | • | • |   | •  |    |    |    | •  |    |    |    | •  |    |    |
|                                      | Developing a knowledge-driven enterprise  | • |   |   |   |   |   |   |   |   | •  |    |    |    |    | •  |    |    |    |    |    |
|                                      | Process integration   |   | • |   | • | • |   |   | • |   | •  | •  | •  | •  | •  | •  |    |    | •  | •  |    |
|                                      | Cost minimization   |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    | •  |    |    |    |
|                                      | Establish a reward system   |   | • |   |   |   |   |   |   |   |    |    |    |    |    | •  | •  |    |    | •  |    |
|                                      | Reducing uncertainty  |   |   | • |   |   |   |   |   |   |    |    |    |    |    | •  |    |    |    |    |    |
|                                      | Enhance brand value   |   |   |   |   |   |   |   | • |   |    |    |    |    |    |    | •  |    |    |    |    |
|                                      | Production and sales capability   |   |   |   |   |   |   |   |   |   |    | •  |    |    |    |    |    |    |    |    |    |
| Quick decision/strategic flexibility |   | • |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    | •  |    |    |    |
| Scholars                             | 1: Haq et al. (2020) [120]; 2:Rasi et al. (2019) [121]; 3: Jermsittiparsert et al. (2019) [122]; 4: Mohammadi (2019) [123]; 5: S`derberg et al. (2018) [124]; 6: Chan et al. (2017) [125]; 7: Bargshady et al. (2016) [108]; 8: Yoon et al. (2014) [126]; 9: Mishra et al. (2014) [127]; 10: Chakraborty and Mandal (2011) [128]; 11:Wu (2019) [129]; 12: Dastyar et al. (2018) [130]; 13: Shahin et al. (2017) [131]; 14: Sangari et al. (2016) [132]; 15:Yang (2014) [133]; 16: Jakhar et al. (2013) [134]; 17: Saleeshya et al. (2012) [135]; 18: Pandey et al. (2009) [136]; 19: Faisal et al. (2007) [137]; 20: Swafford et al. (2006) [119] |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |

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