applied sciences

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Reconfigurable Supply Chain Selection: Literature Review, Research Roadmap and New Trends

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Abstract: The COVID-19 pandemic revealed weaknesses in the global supply chain management. With stock-outs, transportation problems and the bullwhip effect caused by ever-changing demand, it is necessary for decision-makers to review their supply chain configuration. The latter must adapt to new market changes and respond quickly and cost-effectively to customer requirements. In fact, the selection criteria of the most reconfigurable configuration, i.e., the configuration that adapts its structure and its functions to the new market changes, must respond to this problem. The aim of this paper is to conduct a literature review of the criteria and methods for configuration selection in reconfigurable manufacturing systems and reconfigurable supply chains. This study allows to define a roadmap for the configuration selection in reconfigurable supply chains based on the most efficient reconfigurability criteria. We provide new trends to consider in this selection problem. This paper allows managers to choose the most appropriate criteria to implement a reconfigurable supply chain.

Keywords: reconfigurable supply chain; reconfigurable manufacturing system; reconfigurability; configuration selection; roadmap; performance; literature review; sustainability; resilience; vulnerability

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Citation: Zidi, S.; Kermad, L.; Hamani, N.; Zidi, H. Reconfigurable Supply Chain Selection: Literature Review, Research Roadmap and New Trends. *Appl. Sci.* **2023**, *13*, 4561. https://doi.org/10.3390/app13074561

Academic Editors: Marco Bortolini and Francesco Gabriele Galizia

Received: 16 February 2023
Revised: 23 March 2023
Accepted: 28 March 2023
Published: 4 April 2023

1. Introduction

The authors of [1] defined supply chain configuration as a set of supply chain units and links between them, determining the structure of the supply chain and the attributes of the supply chain network. This concept concerns the selection of suppliers, parts, processes and transportation modes at each level of the supply chain [2]. The authors of [3] indicated that this selection can be modified based on the product family for each customer.

From a structural perspective, the supply chain configuration can be considered as a set of nodes and connections between nodes [4], or as a constellation of interconnected elements [5].

From an organizational perspective, supply chain configuration is related to the integration of the company's strategies and operations with the other actors in the chain [6]. In a configurable system, there is a high level of integration among its parts through common strategies and policies that are directed toward common objectives [1].

Furthermore, configuration should be viewed as an evolutionary process and not a dynamic design effort [7]. To put it simply, maintaining a successful supply chain requires adapting its configuration to changing market needs. In fact, for adapting and aligning objectives to new needs, they must be oriented towards dynamic configuration management. Indeed, configuration management is an approach used to identify the characteristics of the functional and physical components of an item in the early phases of its life cycle, to control changes made to these characteristics, and to record and report the processing of changes and the status of their implementation [8]. This configuration management is an important factor in the implementation of systems engineering, including the control and justification of configuration changes [9,10].

The causal link between supply chain configuration and the need for change or reconfiguration is related to the dynamic nature of the supply chain caused by the market's instability and the rapid evolution of new technologies. The author of [10] indicated that configuration management refers to the management of change allowing for the identification and acceleration of modifications. From the same point of view, The authors of [11] considered that configuration is a state designating the complexity of change management at the process level. Research conducted on the concept of supply chain configuration shows that its structuring depends on several factors related to organizational strategies, change strategies and product. Based on this analysis of definitions, we propose the following definition for "Supply Chain Configuration":

> *"Supply chain configuration is the way in which a company organizes its network structurally and functionally in order to adapt quickly and cost-effectively to changing requirements."*

Although several approaches on supply chain configuration are developed, few works have addressed this problem in the context of reconfigurable supply chains. The objective of this paper is to conduct a literature review on the selection criteria of the most reconfigurable configurations in the different levels. This study leads to the proposal of a roadmap for the selection of the reconfigurable supply chain configuration. In this work, we propose concepts that can contribute to improving the selection problem in the context of reconfigurable supply chains. This article aims to answer the following research questions:

- RQ1: What are the criteria for selecting the most reconfigurable supply chain configuration?
- RQ2: What are the steps required to successfully select a supply chain configuration?
- RQ3: What are the new trends to consider in the selection of a reconfigurable supply chain configuration?

The selection of supply chain configuration (warehouse and plant locations, choice of transportation routing, etc.) is becoming a complex decision due to the increase in supply chain actors, which can be considered as a complex network composed of several nodes and interactions. Furthermore, market instability caused by demand variation, customer needs changes, COVID-19 pandemic, political instability, etc., forced companies and decision makers to implement reconfigurable supply chains, i.e., a supply chain able to adapt its structures and functions to cope with market disruptions and changes. This reconfiguration context makes the problem of selecting the most reconfigurable supply chain configuration more complex because

- the criteria for selecting the reconfigurable configuration in a supply chain are not defined;
- the selection of the supply chain configuration involves several actors, i.e., it is a decision that must be made collaboratively;
- the supply chain complexity which is considered as an extended network requires the consideration of various constraints and parameters for a better selection.

Therefore, this paper aims to define the main selection criteria for the configuration of reconfigurable supply chain. Their identification and the study of selection approaches in the context of reconfigurable systems are conducted to propose a roadmap which helps decision makers to succeed in the configuration selection. Finally, new concepts have been proposed to improve the performance of reconfigurable supply chain.

The rest of this article is organized as follows: Section 2 reviews the literature about configuration selection in the context of reconfigurability. A new roadmap for the selection of the most reconfigurable supply chain configuration is described in Section 3. Section 4 presents new trends for the selection configuration in reconfigurable supply chain. Section 5 highlights the managerial and theoretical implications of this work. The concluding remark and recommendations for further works are summarized in Section 6.

2. Literature Review

2.1. Supply Chain Configuration

The strategic and organizational issues involved in the management of supply chain configuration extend largely the structural considerations related to the choice of warehouse locations, modes of transport, etc. Several studies showed that supply chain configurations can be classified in several ways. They can be associated with product configurations, product family design and change strategies.

The authors of [12] chose two types of supply chain strategies derived from a classification related to product types. The first strategy is the "efficient supply chain" related to functional products that include the staples that people buy in a wide range of retail outlets. The second strategy is the "responsive supply chain" related to innovative products that allow firms to increase margins and build customer loyalty.

In the context of strategies for aligning the supply chain with product uncertainties, The author of [13] classified supply chain configurations into four types of strategies where information technology and the internet played an important role in their development. The first strategy is the "efficient supply chain" aimed at optimizing costs. It consists of eliminating non-value-added activities, achieving economies of scale and using optimization techniques for better capacity utilization. The second strategy, called "supply chain risk-hiding", consists of sharing information in real time to reduce the effects of supply chain disruptions. The third strategy is "supply chain responsiveness", which refers to using strategies to be responsive and flexible to changing and diverse customer needs. The fourth strategy is the "agile supply chain" which combines the benefits of the hiding and responsiveness strategies because it has the ability to respond to changing, diverse and unpredictable customer demands upstream, while minimizing the risk of supply disruptions downstream.

In order to determine the attributes needed to design the configuration of supply chains, The authors of [11] proposed a classification based on the state of the supply chain configuration. Indeed, this refers to a "state" that includes data related to the structure of the supply chain, levels of integration, flows, etc. Meanwhile, the configuration refers to a "transformation", which is related to the change in structure, activities, product range, etc.

The authors of [14] distinguished two types of approaches related to supply chain configuration. These are traditional approaches that seek to optimize safety stock placements at each node as well as new approaches representing scenarios where the product design is realized but the logistics options have not yet been chosen.

The author of [15] proposed seven types of supply chain configurations that maximize its ability to respond quickly to new needs, namely collaborative, lean, agile, campaign, fully flexible, supplier converter and hybrid supply chain. In the same perspective, The authors of [16] grouped supply chain configurations under four types of structures including agile, flexible, lean and responsive. Each type allows for the improvement of specific indicators of supply chain performance.

After synthesizing the supply chain configuration approaches, The authors of [17] categorized them based on product, function and operation, and system characteristics. The first type refers to configurations based on product types. The second refers to configurations based on operations and relationships between actors in the chain. The third type is based on the consideration of a supply chain as a system of interconnected units or entities.

Table 1 summarizes the proposed approaches for supply chain configuration.

2.2. Configuration Selection

In this section, we present the different approaches proposed for selection of configurations in the context of manufacturing systems and supply chains reconfiguration. The levels of selection and the criteria used for the choice of the configuration are discussed.

2.2.1. Definition of Configuration Selection

The authors of [18] considered the selection of the optimal configuration as one of the most important choices in the management of reconfigurable production systems and supply chains. This problem of selection includes all the decisions that significantly impact the performance of the systems such as machine layout, equipment selection, management of the system units, etc. The choice of the optimal configuration allows to achieve a significant performance in the different system levels. Configuration selection consists in choosing the best configuration by optimizing the identified criteria for achieving the objectives. The problem of configuration selection is one of the keys aspects that should be considered in order to transform the Reconfigurable Manufacturing Systems' (RMS) implementation from its nascent stage to a mature one [19]. For our research, we propose the following definition:

> *"The Supply chain configuration selection is a decision process which aims to choose the most reconfigurable configuration, i.e., the one which satisfies at most the six characteristics of reconfigurability (modularity, integrability, convertibility, diagnosability, scalability and customization)."*

Table 1. Supply chain configuration approaches.

	Configuration Level		Configuration Types
	Product Design	**Process/Flow Design**	
[12]	√		Efficient supply chain Responsive supply chain
[13]		√	Efficient supply chain Supply chain risk-hiding Supply chain responsiveness Agile supply chain
[11]		√	Supply chain state Supply chain transformation
[14]	√	√	Traditional approaches: stock optimization New approaches: product design
[15]	√	√	Collaborative, lean, agile, campaign, fully flexible, supplier converter and hybrid supply chain
[16]	√	√	Agile supply chain Flexible supply chain Lean supply chain responsiveness Responsive supply chain
[17]	√	√	Product types Operations and relationships between actors System/interconnections in supply chain

2.2.2. Configuration Selection Criteria

The selection criteria are the indicators that must be improved to achieve the objectives defined by the company. These criteria are grouped into two families divided into a set of levels. The first family consists of generic selection indicators which include different performance indicators such as cost, time and reactivity of machines/systems. On the other hand, the second family is composed of indicators related to reconfigurability which consists of three levels of criteria: time and cost of reconfiguration, reconfiguration effort and reconfigurability characteristics. Figure 1 shows the different levels of each indicator family.

1. The generic indicators

This family of selection indicators are those that can be chosen for any selection problem related to the supply chain. Generally, these indicators refer to the performance of the supply chain configuration regardless of its ability to adapt to market changes. These indicators represent selection criteria based on cost, time and capacity.

- The cost: this criterion is considered as the most important one for configuration selection, it includes several types of costs such as investment cost related to expenses for machines or system/supply chain entities such as the implementation of production sites and distribution centers; and logistic costs which are related to the production cost, storage cost, transport cost, etc.

- The time: this criterion refers to all times related to supply chain activities such as production time, total cycle time, lead time, transfer time, processing time, etc.
- The capacity: this criterion refers to the capability of the supply chain to generate outputs (production, etc.) within a given time. The criteria that define this indicator level are, for example, operational capacity, availability, productivity, etc.

2. The reconfigurability indicators

This family of indicators addresses criteria related to supply chain reconfigurability parameters. The authors of [20,21] defined reconfigurability as the ability of the supply chain to change its structure and its functions to adapt to new changes and to cope with market disruptions. In fact, reconfigurability allows judging the supply chain's ability to adapt quickly and cost-effectively to market changes. In this context, three main criteria were used to choose the most reconfigurable configuration, namely the cost/time of reconfiguration, reconfiguration effort and reconfigurability characteristics.

- The cost/time of reconfiguration: the reconfiguration cost is the cost of changing the configuration (adding, deleting or changing the entities that compose it), while the reconfiguration time is the time needed to reach the new configuration.
- The reconfiguration effort: this criterion refers to the change effort (adding, removing, or modifying entities) of a configuration, which measures the transition effort between different configurations [19].
- The reconfiguration characteristics: reconfigurability characteristics (modularity, integrability, convertibility, diagnosability, scalability and customization) allow to achieve high reconfigurability [22–24], reduce reconfiguration effort [25], and can be considered as key indicators for reconfigurability evaluation [20,26].

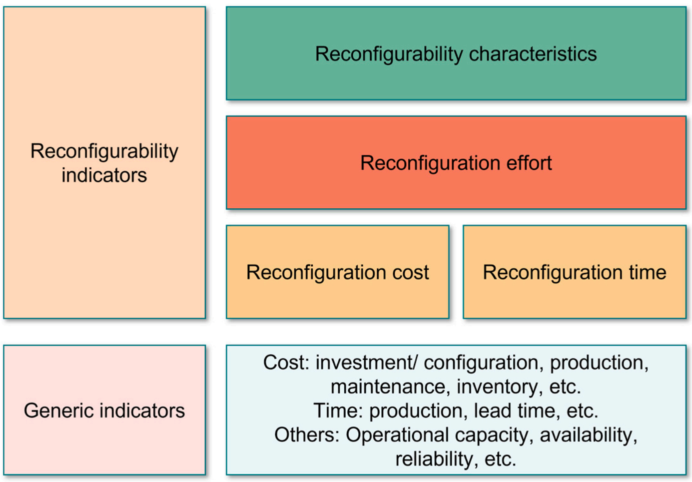

Figure 1. Classification of the configuration selection criteria.

2.3. Configuration Choice Approaches in a Reconfigurable Context

Several approaches and methods are used to solve selection problems. Some approaches are applied to solve single-objective problems and others to solve multi-objective problems. These methods are classified into three categories, namely exact methods based on mathematical models, approximate methods using heuristics and approximation algorithms, and multi-criteria decision-making methods. In this section, the approaches related to the configuration selection problem are classified according to the four families of criteria previously mentioned. This classification allows the identification of the works that considered reconfigurability and its parameters as the fundamental criterion for the configuration selection.

2.3.1. Approaches Using Generic Indicators

To handle the problem of supply chain configuration selection, several works were based on generic criteria in order to improve productivity and increase benefits, especially for the machine level or the system level. The authors of [14] proposed a supply chain configuration selection approach based on the total supply chain cost (production, inventory, procurement, transportation, etc.) using multi-objective programming for formulating the problem and genetic algorithms for the resolution. The authors of [27] addressed the problem of selecting the most optimal machine configuration, i.e., the one with the lowest cycle time. The objective of this selection is to maximize productivity and throughput. The authors of [28] proposed an approach to select the most economical and viable reconfigurable machine tool (RMT) configuration by considering two criteria, namely energy consumption cost as the environmental sustainability and investment cost, and maintenance cost as economic sustainability. In the context of improving companies' competitiveness, Kumar et al. [29] proposed a configuration selection approach based on cost, availability, reliability and operational capability of machines as the selection criteria.

2.3.2. Approaches Using Reconfiguration Indicators

In the context of reconfigurable manufacturing systems and supply chains, several approaches were proposed for the selection of the optimal configuration according to several criteria. The authors of [30] applied the Non-Dominated Genetic Sorting Algorithm (NSGA-II) for the selection of the optimal configuration based on the total cost which consists of the production cost, maintenance cost and configuration change (reconfiguration) cost, as well as the production time and reconfiguration time. Within the same context, [31] proposed an approach to select a set of machines able to perform all the operations required to realize the production using a multi-objective approach based on two criteria, namely the total completion time and the perturbation caused by the unpredicted unavailability of selected machines. The authors of [32] developed a machine selection approach for RMS design to ensure the best process plan that provides customized production. Using NSGA, the authors proposed a multi-objective approach based on maximizing the system flexibility index and minimizing the total completion time.

Based on the reduction of the reconfiguration effort, Youssef et al. [18] proposed a configuration selection approach with several aspects (arrangement of machines, equipment selection and assignment of operations) that consists in minimizing the effort of reconfiguration over a planning horizon based on cost and availability criteria. The authors of [33] proposed a configuration selection approach by considering three criteria, namely cost optimization, machine capacity, and reconfiguration effort which refers to the effort of changing from one configuration to another by applying NSGA-II to determine the set of near-optimal solutions and the Technique for Order Preference by Similarity to Ideal Solution method to rank the pareto frontiers. In their proposed approach, Ashraf and Hasan [19] also included cost, capacity and reconfiguration effort as part of the production line configuration selection. The authors of [34] introduced a new composite metric for product flow configuration selection for RMS that included nine relevant factors, namely investment cost, reconfiguration time, product lead time, throughput, reliability, system availability, operational capability and reconfiguration effort/smoothness.

Despite their importance in selecting the optimal configuration, few works have focused on reconfigurability characteristics for configuration selection in the context of reconfigurable manufacturing systems and supply chains. The authors of [35] addressed the configuration selection problem to determine the optimal configuration based on four fundamental criteria, namely productivity, convertibility, scalability and cost which can be applied to other types of manufacturing systems. The authors of [36] proposed an approach to configuration selection in RMS based on their degree of reconfigurability at both the system and machine level measured according to three indicators: modularity, convertibility, diagnosability. In the same context, Kumar et al. [37] presented a comprehensive decision making approach for selecting an optimal configuration for the single part reconfigurable flow line based on cost, machine utilization, operational capacity, machine reconfigurability and configuration convertibility, which represent the selection criteria. Based on the six reconfigurability characteristics, Zidi et al. and Zidi et al. [20,26] proposed an approach to evaluate reconfigurability by formulating these characteristics mathematically. This approach allows to choose the most reconfigurable configuration objectively and from a quantitative evaluation, while considering the uncertainty in the decision-making process.

Table 2 shows a classification of the proposed approaches in the context of configuration selection according to the application levels, criteria and methods used.

Table 2. Classification of configurations selection approaches proposed in the context of reconfigurability.

	Selection Level			Criteria Selection					Methods		
	Machine	System	Supply Chain/Network	Generic Indicators	Reconfigurability Indicators				Mathematical Models	Metaheuristic	Multi Criteria Decision Making
					R-Cost	R-Time	R-Effort	R-Characteristics			
[18]		√		√			√			√	
[14]			√	√					√	√	
[33]	√			√			√			√	√
[30]	√			√	√	√				√	
[35]		√		√				Convertibility and scalability			√
[31]		√		√		√				√	
[27]	√			√						√	
[32]		√		√		√				√	√
[36]	√	√					√				√
[19]		√		√			√			√	√
[34]		√		√		√	√				√
[29]		√		√					√		
[37]	√			√			√	Convertibility			√
[28]	√			√					√	√	
[20]			√		√	√		√	√		√
[26]			√		√	√		√	√		

R-cost Reconfiguration cost; R-time: Reconfiguration time; R-effort: Reconfiguration effort; R-characteristics: Reconfigurability characteristics.

3. New Roadmap for Supply Chain Reconfiguration Selection

3.1. Supply Chain Reconfiguration Needs

To create a competitive advantage, decision-makers are challenged to adapt to new market requirements and to implement new technologies. Supply chain management has become increasingly complex due to globalization and its effects. The increased complexity of the supply chain causes high operational costs that must be minimized to ensure effective collaborative supply chain management [38,39]. To survive in this volatile environment, companies must transform their supply chains into a network that adapts to new needs. This ability to change the supply chain configuration is a crucial factor for business success [40].

To remain competitive in the market, companies must build a supply chain that is able to change its configuration and adapt it to new requirements quickly and cost-effectively. Therefore, the need for reconfiguration occurs to improve the supply chain's performance [41]. The authors of [1] consider supply chain reconfiguration as a viable solution to meet changing customer demands and to cope with the fluctuating market environment.

The need for reconfiguration can be triggered by a disruptive event which requires a quick reaction or a decision to improve supply chain performance even if there is no failure. Thus, we identify two types of events that create the need to reconfigure supply chains.

- Reconfigure to respond to market disruptions:

The need for reconfiguration is usually triggered by a hazard or disruptive event that causes a partial or total dysfunction in the supply chain. This event occurs as a result of failures and unexpected problems that can affect the functioning of supply chains on the strategic, tactical and operational decision levels (demand fluctuation, geopolitical instability, stock shortage, delivery problem, etc.). Figure 2 illustrates the triggering mechanism of the reconfiguration need due to a disruptive event.

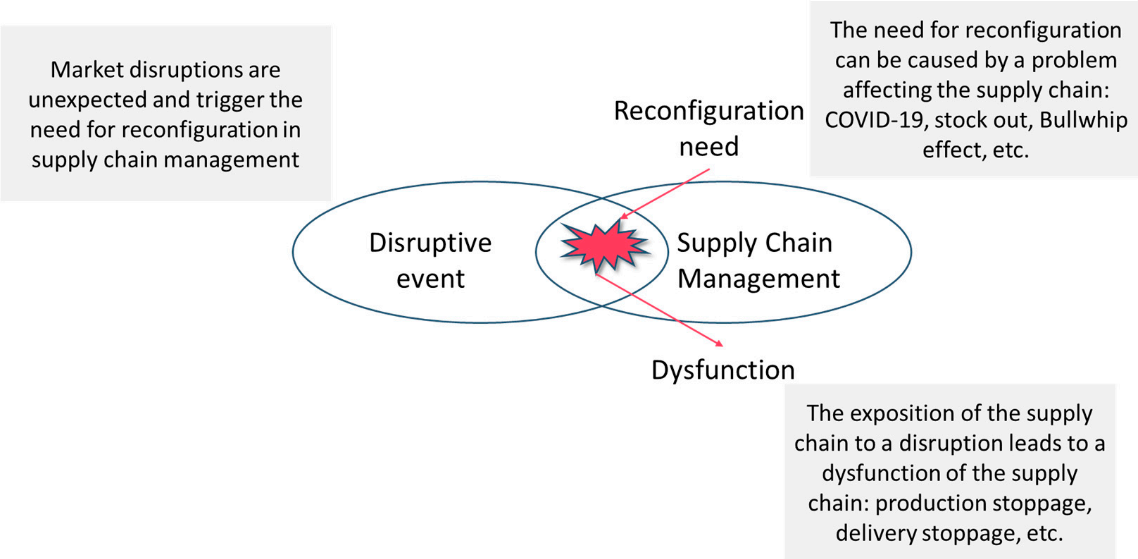

Figure 2. Impact of the disruptive event on supply chain management.

- Reconfigure to improve supply chain performance:

The emergence of new technologies (Industry 4.0, etc.) and continuous improvement processes require the implementation of reconfiguration strategies without the need for a hazard event to trigger the need for change. This type of reconfiguration can be deployed as a part of an innovation strategy to improve the operational and organizational performance of the supply chain (AGV, autonomous robots, warehouse redesign, etc.). In this case of reconfiguration, the advantage is to change without having a supply chain dysfunction; the objective is to avoid being outdated and to meet new market trends. Figure 3 illustrates the triggering mechanism of the reconfiguration need for innovation.

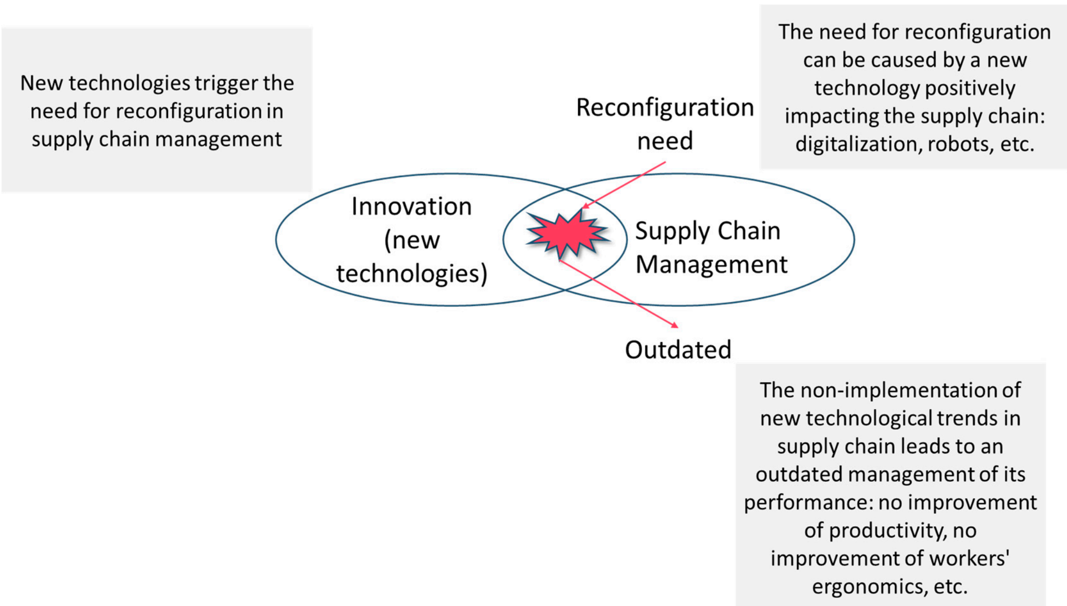

Figure 3. Impact of the innovation on supply chain management.

3.2. Proposed Roadmap

The proposed roadmap of selecting the most reconfigurable supply chain configuration starts with analyzing the existing system by clarifying the company's reconfiguration objectives and identifying the resources needed. Decision makers must align objectives with available resources. The second phase concerns the choice of reconfigurability criteria allowing the selection of the most reconfigurable configuration. These criteria depend on the reconfiguration objectives defined in the first phase. The third phase of this roadmap consists in the reconfigurability evaluation, allowing the decision makers to measure the gaps between the defined reconfigurability objectives and the selected supply chain configuration. Finally, the fourth phase ensures the continuous improvement of reconfigurability to increase the supply chain's ability to cope with disruptions and go beyond the defined reconfiguration objectives. Figure 4 shows the selection phases of the most reconfigurable supply chain configuration and the different concepts to be integrated in the proposed roadmap.

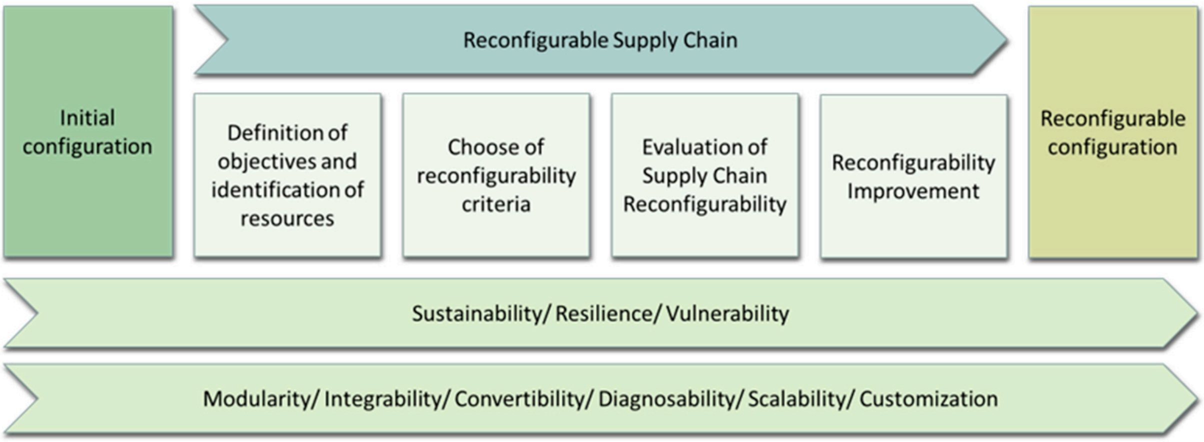

Figure 4. The proposed roadmap for the selection of the most reconfigurable supply chain configuration.

The design of the roadmap was based on the main results of the literature review conducted. The studied approaches show that choosing the configuration selection criteria in a reconfigurable context requires identifying the reconfiguration objectives and providing the necessary resources to achieve them. This step allows to better choose the selection criteria of the most reconfigurable configuration. For example, to increase the production capacity in a manufacturing plant or to increase the capacity of processed orders in a distribution center, the key selection criterium is scalability.

After selecting the reconfigurable configuration, decision makers should ensure the evaluation of their supply chains' reconfigurability to measure the gaps between the defined objectives and the obtained results. This evaluation step enables the final step of continuously improving supply chain performance related to its ability to adapt to market changes.

For example, after the COVID-19 crisis, most companies faced supply and delivery problems caused by confinements. Today, companies need to review their current supply chain management by prioritizing the availability of multiple suppliers to provide the necessary raw materials, implement new technologies to ensure their productivity and reduce the impact of problems affecting the supply chain processes.

3.2.1. Definition of Objectives and Identification of Resources

While supply chain reconfiguration is a solution for managers to cope with market changes, it can be costly and requires significant time to implement. For this reason, it is important to define the scope of application of supply chain reconfiguration, i.e., internal/external, upstream/downstream, or the entire supply chain. The reconfiguration objectives must be well defined depending on the material and non-material resources needed to meet them. This step requires the use of collaboration tools between all the stakeholders of the reconfiguration project (meeting, brainstorming, etc.). To make the reconfiguration objectives explicit, clear and SMART (Specific, Measurable, Achievable, Realistic, Timely), it is recommended to associate them with the reconfiguration and its characteristics (modularity, integrability, convertibility, diagnosability, scalability, customization). Indeed, this allows the company to know how to achieve the desired objective, and which characteristic needs to be focused on in order to optimize the utilization of the resources. For example, if the company aims to increase its production capacity, scalability is the characteristic that can guide decision-makers towards achieving this objective.

3.2.2. Choose of Reconfigurability Criteria

The choice of supply chain configuration depends on the company's objectives. In the context of reconfigurable supply chains, the most reconfigurable configuration must meet the needs of the reconfiguration and its characteristics previously mentioned. This means that in the design or redesign phase of supply chain configuration, it is recommended that it be modular, integrable, convertible, diagnosable, scalable and customizable. The works of [20,21,26] describe how to consider these characteristics in the supply chain and how to choose the configuration that ensures the highest degree of reconfigurability. For this phase, several methods can be applied for choosing the most reconfigurable configuration, either multi-criteria decision support methods or heuristic/metaheuristic methods. The method adopted for solving this problem depends on several factors, for example the available data, the difficulty of the problem, the objectives, etc. In this phase, the decision makers have to choose the criteria for selecting the most reconfigurable supply chain configuration to respond to the defined objectives. In Section 2, a literature review was conducted to identify the different criteria chosen for the selection of configurations in the context of reconfigurable systems. We recommend the choice of the reconfigurability characteristics previously mentioned to select the most reconfigurable configuration because they guarantee to cope with the market changes and to meet the customers' requirements in the shortest time and cost effectively.

3.2.3. Evaluation of Supply Chain Reconfigurability

The reconfigurability evaluation of the supply chain configuration is an important phase in the selection process of the most reconfigurable configuration. To improve reconfigurability, it is necessary to define indicators to measure and evaluate it objectively. Several indicators can be used to assess reconfigurability, i.e., to evaluate the ability of the supply chain to adapt its structure and functions to market changes [42]. In the latter, the authors have identified several indicators that can be used to evaluate reconfigurable supply chain performance (changeability, resilience and robustness, reliability, flexibility, agility). It is recommended to assess reconfigurability based on the six characteristics of reconfigurability as presented in [20,26] because the presented evaluation model is based on quantitative indicators that require easily collected data to objectively assess the reconfigurability of supply chains.

3.2.4. Reconfigurability Improvement

The evaluation of supply chain reconfigurability identifies the gaps between the defined reconfiguration objectives and the implemented actions. In order to overcome these gaps, decision-makers should define an action plan to quickly address the need for supply chain reconfiguration. Reconfigurability improvement actions depend on modularity, integrability, convertibility, diagnosability, scalability and customization. The reconfigurability improvement phase improves the ability of the supply chain to cope with market changes and disruptions continuously. While implementing a reconfigurable supply chain enables managers to respond quickly and cost-effectively to market changes, disruptions affecting supply chain performance that are sometimes unpredictable and difficult to detect require continuous reconfigurability improvement with minimum reconfiguration effort. This improvement process must include several new perspectives that are constantly emerging in recent years, namely the sustainability and circular economy challenge, supply chain resilience and supply chain vulnerability.

4. New Perspectives for Reconfigurable Supply Chain Selection

The implementation of reconfigurable supply chains is an effective solution for decision makers to bridge failures and cope with market disruptions and changes. However, in recent years, several concepts have emerged which remain important for an optimal and successful supply chain design. Therefore, it is important to consider these concepts in the design of reconfigurable supply chains, namely sustainability, resilience and vulnerability, as shown in Figure 5.

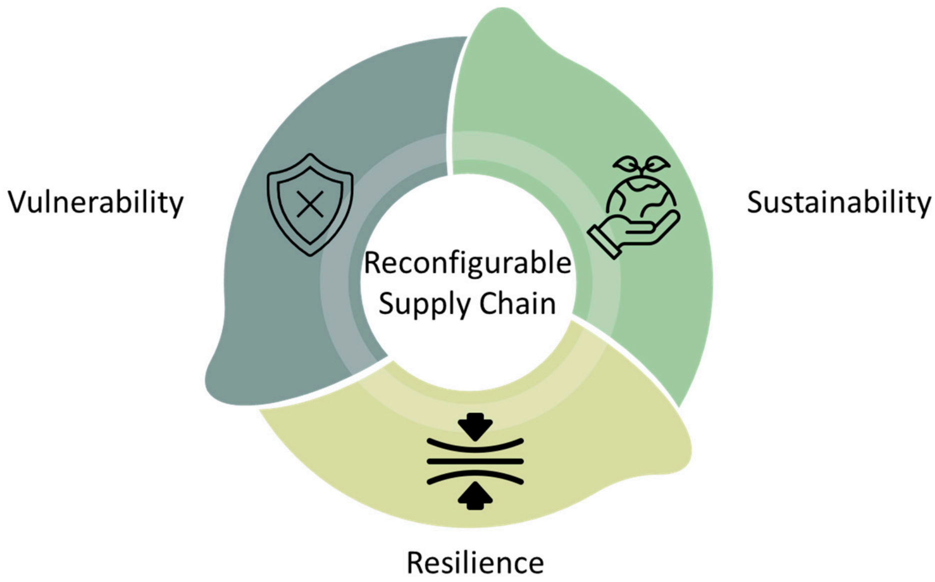

Figure 5. New trends for Supply Chain Configuration in RSC.

4.1. Sustainability

Environmental, social and economic issues remain a fundamental requirement for supply chain configuration. Although this concept has been widely discussed in the literature for many years, sustainability has acquired a new dimension in recent years due to growing energy problems. Several works emphasize the importance of sustainability in future manufacturing and in the society 5.0. The author of [43] conducted a study on the role of sustainability in Industry 5.0 and its positive impact on supply chains and production systems. To clarify how Industry 5.0 can deliver sustainability values, Ghobakhloo et al. [44] conducted a content-focused literature synthesis leading to the identification of several functions through which Industry 5.0 can promote sustainability values in terms of resilience, environmental sustainability and human centricity. The author of [45] proposed a framework of Industry 5.0 through the model of the viable supply chain, the reconfigurable supply chain and the human-centered ecosystems, from which sustainable society can be the result of this future industry. In the reconfigurable context, sustainability is becoming important in RMS research [46–52]. In these works, the authors highlighted the role of RMS in guaranteeing aspects of sustainability. On a larger level, the sustainability of supply chains should be the object of the design parameters of the supply chain configuration, especially in the implementation of reconfigurable supply chains. The challenge is to answer the following questions:

- How can reconfigurable supply chain contribute to sustainability and improve environmental, social and economic aspects?

- How to improve the ability of the supply chain to adapt to rapidly changing sustainability requirements?

4.2. Resilience

The COVID-19 crisis, geopolitical uncertainty, etc., have significantly impacted supply chain management. Indeed, supply chains must be resilient to mitigate the effects of market disruptions and be able to withstand them. This concept has largely emerged in the context of supply chains after the COVID-19 pandemic. In this context, Paul et al. [53] showed the important role of resilience and sustainability in supply chain to deal with market disruptions. In the context of reconfigurable supply chains, Dolgui et al. [41] showed the role of resilience in reconfigurable supply chains in both proactive (pre-disruption decision-making) and reactive (devoted to recovery planning) domains. Several reactive and proactive approaches have proved their effectiveness in building resilient supply chains in their restructuring after the COVID-19 pandemic [54]. The authors of [55] showed the important role of reconfiguration in ensuring a resilient supply chain, as supply chain reconfigurability is characterized by structural and process variety which is beneficial for supply chain resilience [45,56]. All these works show the high correlation between reconfigurability and resilience of supply chains. It is important in future work to answer the following questions:

- How can resilience be a criterion for selecting the reconfigurable supply chain configuration?
- How can the resilience of the supply chain be guaranteed through the six reconfigurability characteristics?

4.3. Vulnerability

Risk management in supply chains is becoming more and more complex, especially after the COVID-19 pandemic, which severely impacted current risk management strategies. The authors of [57] explained the role of risk management in mitigating the effects of market disruptions on supply chain resilience. The authors of [58] emphasized the role of supply chain reconfiguration in minimizing the impacts of COVID-19. In the same context, Ivanov and Ivanov [59–61] proposed a viable supply chain (VSC) to integrate sustainability, resilience and agility by showing the role of this model in the reconfiguration of supply chains after the COVID-19 pandemic.

In an unstable and uncertain market context, the vulnerability of supply chains should be considered as a criterion for selecting the reconfigurable supply chain configuration to ensure a viable and resilient supply chain, i.e., less exposed to risks and market disruptions. This concept can be explained with the notion of the sponge effect (characterized by the phenomenon of absorption and adsorption) of the supply chain, i.e., the ability of the supply chain to absorb market needs and requirements while remaining unaffected by market risks and disruptions as shown in Figure 6. The absorption of market needs is achieved by ensuring a reconfigurable supply chain, which is defined as the ability to meet customer needs by changing the structure and functions of the supply chain. Adsorption refers to the ability of the supply chain to cope with market disruptions by ensuring resilience/viability to reduce its vulnerability. In future work, it is recommended to answer the following question:

- How can choosing the most reconfigurable supply chain configuration reduce its vulnerability?

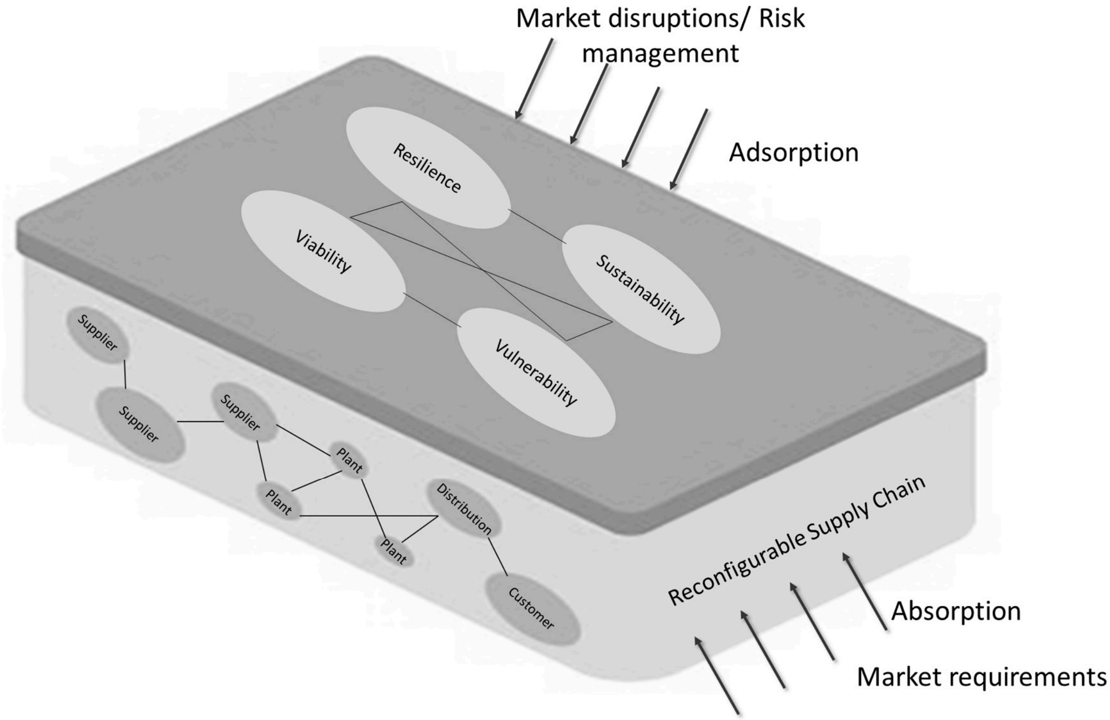

Figure 6. Sponge effect in Reconfigurable Supply Chain.

5. Managerial and Theoretical Implications

From a managerial point of view, this article aims to help managers and decision makers to choose the criteria for selecting the most reconfigurable configuration. This choice of configuration ensures a supply chain that adapts with market disruptions by changing its structure and functions. The process of supply chain configuration selection requires a detailed analysis of the different market requirements and the available resources. For this reason, it is important to focus on the selection criteria of the most reconfigurable configuration to optimize the selection process. The analysis carried out in this paper has shown that the six reconfigurability characteristics (modularity, convertibility, integrability, diagnosability, scalability and customization), the reconfiguration effort and the reconfiguration time/cost are the most used criteria in the context of reconfigurable supply chains due to their proven effectiveness in the selection process of the most reconfigurable configuration. This work provides decision makers with new concepts and trends to consider in the context of implementing reconfigurable supply chains, which can be considered in the configuration selection process, namely sustainability, resilience and vulnerability.

From a theoretical point of view, several works have addressed the problem of configuration selection especially in RMS based on several criteria directly or indirectly associated with the reconfigurability concept. However, this problem was not developed at the supply chain level. Theoretically, this work opens new perspectives for the development of supply chain design models to cope with market disruptions. In this paper, we have identified potential criteria for selecting the most reconfigurable supply chain configuration.

The proposed roadmap is the result of the study of configuration selection approaches in a reconfigurable context, as well as the selection criteria related to reconfiguration aspects. The proposed work provides decision makers with a method to successfully implement a reconfigurable supply chain. The applicability of this roadmap is obvious because the objective is to know the essential phases to select the supply chain configuration according to its reconfigurability. Its evaluation is considered feasible and applicable in [20,26]. We consider that this work is feasible for any type of company aiming to implement a reconfigurable supply chain because the proposed roadmap simply requires an understanding of the identified reconfiguration objectives, an objective choice of the configuration selection criteria based on the reconfigurability aspects, the evaluation of the reconfigurability based on the metrics proposed by [20], as well as the implementation of an action plan ensuring a continuous improvement of reconfigurable supply chain performance.

6. Conclusions

In this paper, a literature review of articles dealing with the problem of selecting the most reconfigurable configuration in manufacturing systems and supply chains was conducted. The results of this paper provide a roadmap to select the most reconfigurable supply chain configuration based on the most efficient criteria.

The results of the literature review provided the different criteria for selecting configurations in a reconfigurable context. The identified criteria can be directly associated to the reconfigurability, i.e., reconfigurability characteristics, reconfiguration effort, reconfiguration cost/time or criteria that are indirectly associated to the reconfigurability, i.e., reliability, lead-time, etc. These results provided a first step for the proposal of a roadmap to select the most reconfigurable configuration of supply chains. The roadmap consists in defining the reconfiguration objectives, choosing the selection criteria, evaluating the reconfigurability and improving it. Finally, new concepts were proposed for their consideration in future models of reconfigurable supply chain configuration selection, namely sustainability, resilience and vulnerability. These results build a solution for decision makers to implement a supply chain that adapts with the different customer requirements and copes with market disruptions based on efficient and objective selection criteria.

This paper has two main limitations. The first limitation of this work is the non-application of this roadmap in a real case to determine its applicability. Indeed, this proposed roadmap is the result of a deep literature review, and it is recommended to support it with a real application to show its industrial applicability. The second limitation of this work is related to the concepts of resilience, sustainability and vulnerability which are considered as new trends to be considered in the selection models of the most reconfigurable configuration. Indeed, this work shows "what" to include in the selection process of the most reconfigurable configuration, but not the "how" and the necessary steps to include them.

For future work, it is recommended to validate the proposed roadmap in several real-world application cases by considering reconfigurability characteristics as selection criteria. A comparison between the application results of the proposed roadmap is also suggested to investigate its feasibility and effectiveness in several industrial sectors. Furthermore, it is important to develop a more detailed methodology explaining how to integrate sustainability, resilience and vulnerability in the selection model of the most reconfigurable supply chain configuration by identifying the key criteria related to each concept.

Author Contributions: Literature review, S.Z. and H.Z.; methodology, S.Z., H.Z., N.H. and L.K.; perspectives, S.Z., H.Z., N.H. and L.K.; writing—original draft preparation, S.Z., H.Z.; writing—review and editing, S.Z., H.Z., N.H. and L.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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